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ATTACHMENT 2

Development of a Remote Monitoring System Using Meteor Burst Technology

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ABSTRACT

Monitoring the cleanup and closure of contaminated sites requires extensive data acquisition, processing, and storage. At remote sites, the task of monitoring often becomes problematical due to the lack of site infrastructure (i.e., electrical power lines, telephone lines, etc.). MSE Technology Applications, Inc. (MSE) has designed an economical and efficient remote monitoring system that will handle large amounts of data; process the data, if necessary; and transmit this data over long distances. Design criteria MSE considered during the development of the remote monitoring system included: the ability to handle multiple, remote sampling points with independent sampling frequencies; robust (i.e., less susceptible to moisture, heat, and cold extremes); independent of infrastructure; user friendly; economical; and easy to expand system capabilities.

MSE installed and tested a prototype system at the Mike Mansfield Advanced Technology Center (MMATC), Butte, Montana, in June 2005. The system MSE designed and installed consisted of a "master" control station and two remote "slave" stations. Data acquired at the two slave stations were transmitted to the master control station, which then transmits a complete data package to a ground station using meteor burst technology. The meteor burst technology has no need for hardwired landlines or man-made satellites. Instead, it uses ionized particles in the Earth's atmosphere to propagate a radio signal. One major advantage of the system is that it can be configured to accept data from virtually any type of device, so long as the signal from the device can be read and recorded by a standard datalogger. In fact, MSE has designed and built an electrical resistivity monitoring system that will be powered and controlled by the meteor burst system components.

As sites move through the process of remediation and eventual closure, monitoring provides data vital to the successful long term management of the site. The remote monitoring system developed by MSE is cost effective, robust, and can easily be integrated into a site monitoring plan yet remains independent of other site activities/infrastructure and is expandable to meet future site monitoring requirements.

INTRODUCTION

Under the FY05 task TSF-Sensors & Monitoring, MSE Technologies, Inc. (MSE) is providing support to address the sensor and monitoring needs of the Department of Energy (DOE). With input from various closure sites, MSE has identified site monitoring needs and the status/availability of technologies to meet those needs. Site monitoring, especially post-closure monitoring, typically requires extensive data acquisition, processing, and storage. Monitoring is further hindered as site infrastructure (i.e., electrical power lines, telephone lines, etc.) is removed. MSE has designed an economical and efficient remote monitoring system with the ability to handle large amounts of data, process the data, if necessary, and transmit this data over long distances. This system is solar-powered and relies on meteor burst technology to transmit data from a remote field location. The meteor burst system does not require hardwired landlines or man-made satellites for data transmission. The initial, prototype system was installed at the Mike Mansfield Advanced Technology Center (MMATC), Butte, Montana, in June 2005. This document describes the prototype system that was installed.

METEOR BURST TECHNOLOGY BACKGROUND

Meteors passing through the upper atmosphere (80- to 120-km region) create trails of ionized particles in the Earth's atmosphere. In the 1950s, after it was discovered that the ionized trails were capable of reflecting radio waves transmitted from the Earth's surface, the military began communication experiments using the ionized trails. By 1975 the Natural Resources Conservation Service (NRCS) had incorporated a meteor burst communications system into the SNOTEL (SNOwpack TELemetry) system to monitor rain and snowfall levels at remote stations throughout the Rocky Mountains.

Meteor trails are typically tens of kilometers long and can reflect radio signals over distances of up to 2000-km (1200-miles) between a transmitter and receiver. Transmission time can vary since the ionized particle rapidly diffuse into the air, losing the ability to reflect radio waves. Most meteor trails last less than 1 second. However, a large meteor may create an ionized trail capable of reflecting radio waves for up to several minutes. Fig. 1 illustrates how the meteor burst technology works.

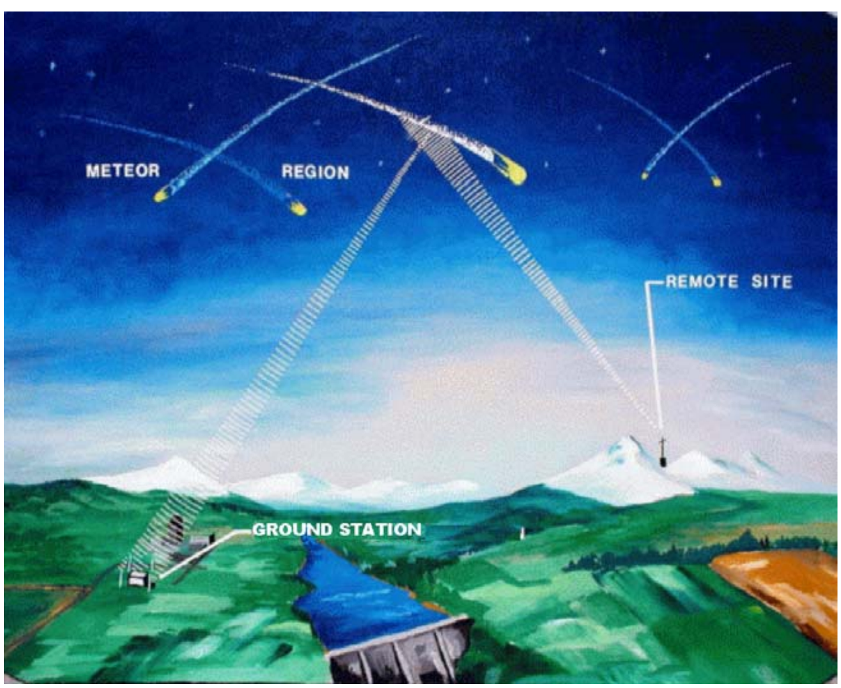


Fig. 1. Illustration of Meteor Burst technology operation

Standard operation of a system is as follows: (1) a ground station transmits a continuous, coded signal, in the Low Band VHF region (40- to 50-Mhz); (2) when an ionized trail appears in the desired location, the signal is propagated via reflection or refraction to a remote site; (3) the remote site decodes the signal, turns on its transmitter and transmits a signal back along the same path to the ground station. Because the ionized trails typically exist for only a few milliseconds to a few seconds, communication is intermittent, and high-speed digital transmission techniques must be used. Hence, "bursts" of data are transmitted and received. Depending on the time of day, time of year, and system design factors the wait-time between finding suitable, ionized trails can range from a few seconds to minutes.

ADVANTAGES OF METEOR BURST TECHNOLOGY

The meteor burst technology is an alternative to standard, man-made satellite data transmission and has several advantages. There is a two-way communication between the ground station and the remote site, which greatly reduces the chance of data loss. Data can consist of short messages (i.e., sensor data), coded messages of up to several hundred characters, text messages of a few words, or long messages transmitted in successive "bursts." The data "burst" feature makes it possible for multiple links to share a common frequency. The meteor burst system does not require equipment to be placed in orbit. Operation costs can be reduced because expensive satellite time rental can be avoided. Finally, meteor burst data transmission it is not susceptible to many natural and man-made atmospheric disturbances (e.g., aurora borealis and fouling due to nuclear explosions), which often render other satellite systems inoperable.

MSE REMOTE MONITORING SYSTEM

The characteristics MSE identified as being key to designing/ building an effective remote monitoring system include:

- Ability to handle multiple, remote sampling points with independent sampling frequencies;
- Robust (i.e., less susceptible to moisture, heat, and cold extremes);
- Independent of infrastructure;
- User friendly;
- Economical; and
- Easy to expand system capabilities.

The prototype remote monitoring system MSE designed and installed at the MMATC consisted of a "master" control station, two remote "slave" stations, and an electrical resistivity monitoring system. Data acquired at the two slave stations are transmitted to the master control station using radio telemetry. Data from the electrical resistivity is stored directly to the datalogger in the master control station. The master control station then transmits a complete data package to a ground station via the meteor burst technology. The components of the prototype remote monitoring system are described in more detail in the following sections.

Master Control Station

The master control station, shown in Fig. 2, is made up of 6 major components: a meteor burst antenna; a meteor burst panel; a 900 MHz radio antenna; a solar panel; a battery charge controller; and batteries.

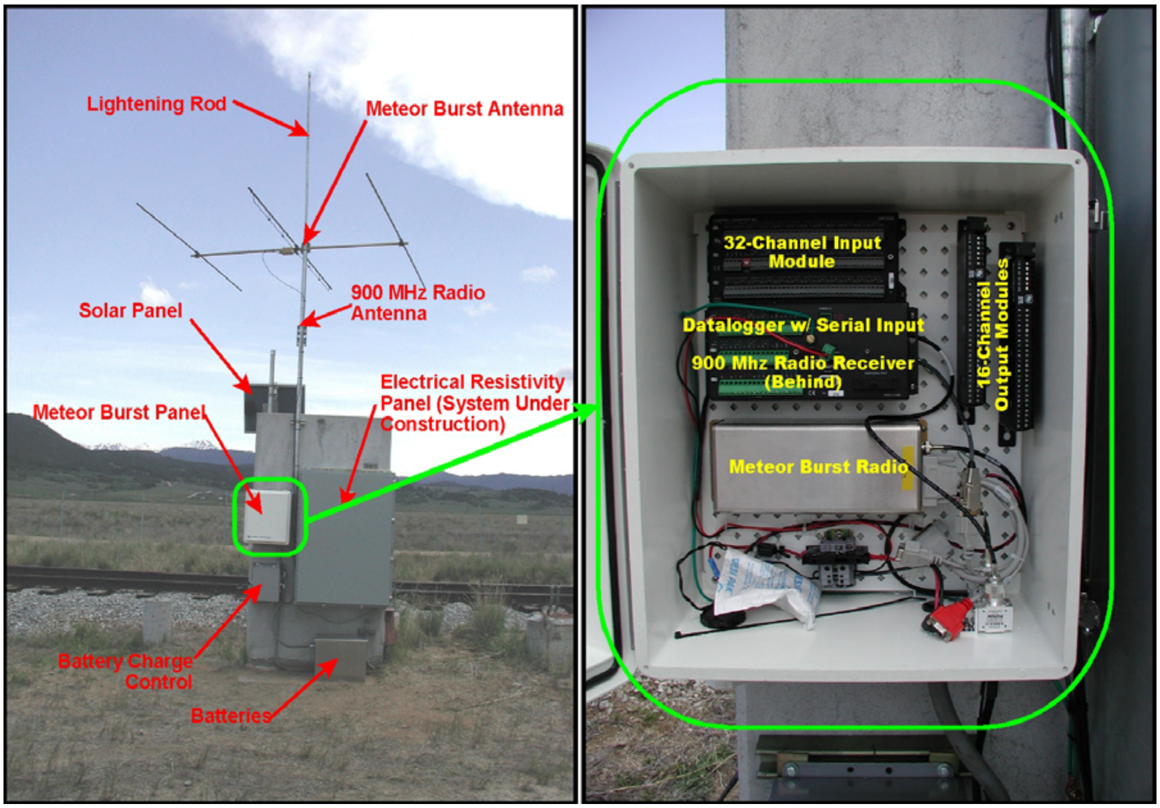


Fig. 2. Photo of master control station and Meteor Burst panel components

This equipment provides the primary datalogging and transmitting functions. The electrical resistivity panel is for an electrical resistivity system that MSE is currently designing for use with the meteor burst system. A close–up view of the meteor burst panel components is shown in Fig. 2.

Data from the sampling units are transmitted to the meteor burst panel via a 900-MHz telemetry system. Additional input and output channels were included in the design to accommodate the electrical resistivity system.

Remote Slave Units

Two remote slave units were installed as part of the initial remote monitoring system. A pressure transducer placed down a site monitoring well provided a data source for the slave units. Fig. 3 shows the setup for each of the slave units.

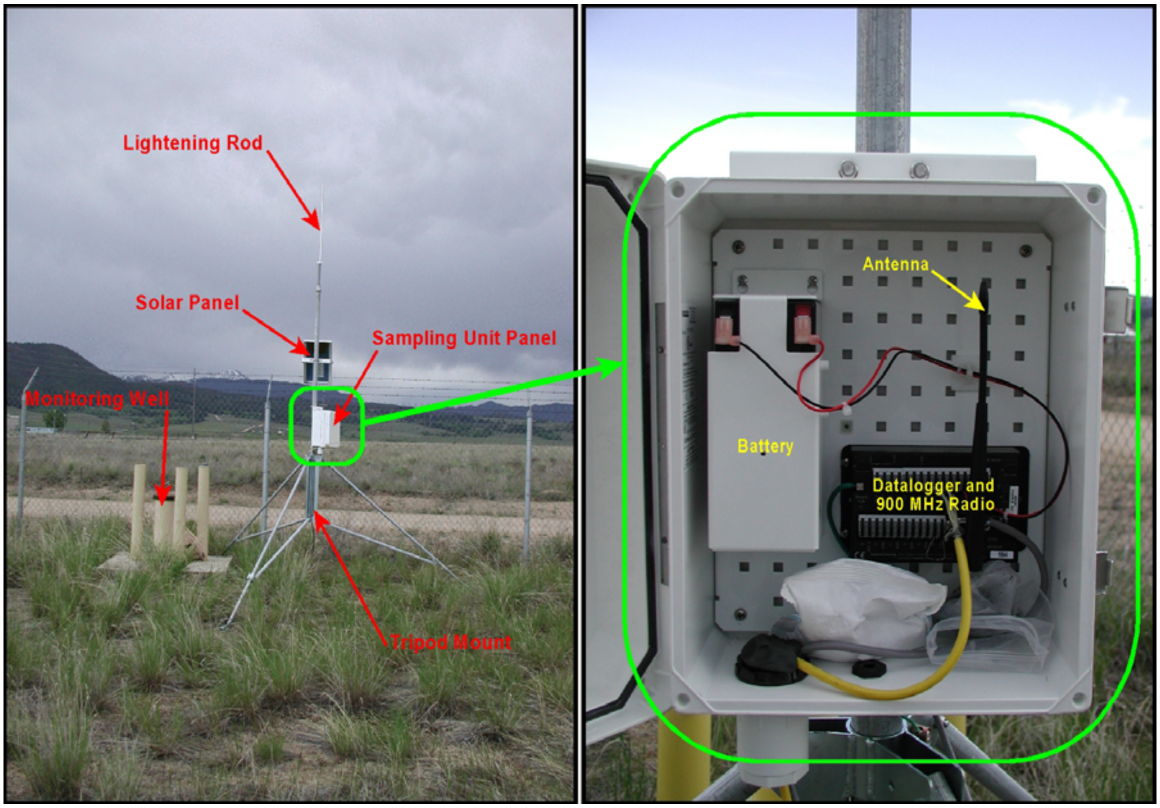


Fig. 3. Photo of remote slave unit and sampling unit panel components

The major components of the remote slave units included: a sampling unit panel; a solar panel; and a tripod mount. A close–up view of the sampling unit panel components is shown in Fig. 3. Data from the pressure transducers are acquired at the top of every hour and transmitted to the main control unit.

Electrical Resistivity Monitoring System

Electrical resistivity has been frequently used for characterization and monitoring of the subsurface. These methods can be an effective tool for long term monitoring of installations such as landfills and subsurface barriers because electrical resistivity methods can provide an early warning system; require a much lower sensor density than conventional methods assuming same level of coverage and information returned to users; and can be automated and results correlated with other types of monitoring data such as water levels. Electrical resistivity methods can provide spatially integrated measurements and be scaled to meet the monitoring objectives of most sites. However, existing electrical resistivity systems have several limitations, including: requiring large amounts of power to make measurements; expensive; automation requiring a computer that must be protected from adverse weather; and data transfer requiring infrastructure.

MSE designed a relatively simple resistivity system that works in conjunction with the meteor burst system. The system can be used to acquire both self-potential data and low frequency electrical resistivity data. This system is totally self-contained and does not rely on external supporting infrastructure at the site. It is solar/battery powered and has a 100-volt, 2-amp power supply. To reduce costs the resistivity system does not include extra features that are found in most commercially available electrical geophysical measurement systems. While these features are important for many applications; they are not necessary for a monitoring system. The MSE system is currently setup for 11 electrodes. With additional hardware costs, the system could be easily expanded to allow the desired number of electrodes. Additional meteor burst transmission costs may also be required depending on the number of additional channels.

DATA MANAGEMENT

Data acquired from the remote sampling locations and electrical resistivity system can be stored in the datalogger in the main control unit panel. The datalogger has some data processing capabilities. Multiple processing routines can be uploaded directly to the datalogger. The two-way communication between the ground station and the master control station allows for switching between these routines, if necessary. Data is stored at the main control unit the pre-defined transmission time is reached. At this time the system will search for a suitable, ionized trail(s) so that it can transmit the data to the ground station. Once received, data are then posted to the Internet. The data formatting is simple and can be accessed for further processing with little difficulty.

ACKNOWLEDGEMENTS

Work was conducted through the U.S. Department of Energy (DOE) Environmental Management Consolidated Business Center at the Western Environmental Technology Office under DOE Contract Number DE-AC09-EW96EW405.

NRCS

Snow Survey & Water Supply Forecasting Program

Web site: www.wcc.nrcs.usda.gov November 28, 2006

Snow Survey Centennial Celebration
1906-2006

SNOTEL ELECTRONICS HISTORY

Prior to the advent of the meteor burst radios, a small remote sensing program was on going at Utah State University (USU), Logan, Utah. Beginning in 1964, a professor and some students of the water resources department remotely measured five mountain sites for snow water and precipitation. The radios they used were two watt CB's (citizen band) with weighting type transducers. The sites were interrogated by flying over them in a fixed-wing aircraft and counting tones, which were than graphed to estimate their measurements.

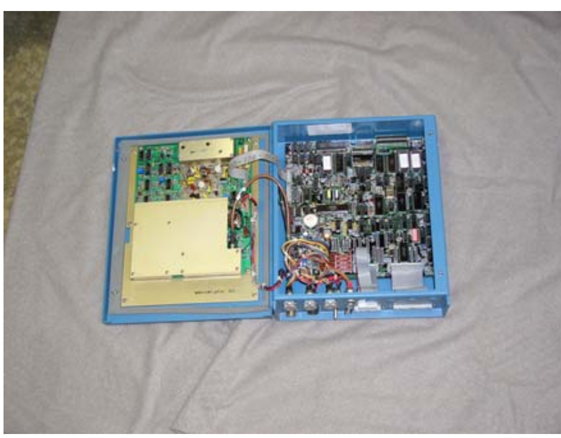
A new generation of radio was introduced in 1966. The radios were developed using a Motorola transmitter and receiver, along with a network of mountain top repeaters. This system allowed the researchers to interrogate the electronic data sites from their office. The project personnel were also doing some measurements for the Bureau of Reclamation, which was studying the results of cloud seeding. The study lasted 6 years. In 1972, the combined efforts of USU and Thiokol Corporation created what was called the Hydrologic Telemetry (HiTel) system, which would be expanded in the coming years, collocating their electronic equipment with existing manually read snow courses . The radios were now operating on 172.55 MHz and the system was expanded to 15 HiTel sites that were adjacent to snow courses established and maintained by the USDA-Soil Conservation Service.

In 1975, the USDA-Soil Conservation Service began the initial planning to convert snow courses in key watersheds to obtain near real-time hydrologic data. A new radio technology was needed and a contract to Western Union was awarded. Western Union contracted with Secode Electronics, which was the manufacturing arm of Communications Industries, to supply meteor burst radios. In the back room of the radio design was a team of Boeing engineers. Boeing was interested in meteor burst technology for military applications. This small team was formed in 1975 under the name of Meteor Communications Consultants (MCC). In 1980, this team became known as MeteorComm Corporation (MCC). Western Union contracted to install and maintain the first meteor burst sites, which were called SNOTEL (SNOw TELemetry), using the Metracom radio. Within a short time, it became evident that the job of keeping an operational, real time data base running was a bigger job than Western Union could handle. The Soil Conservation Service started to staff up with their own electronic and hydrologic technicians to install and maintain the SNOTEL network, with the first ones coming on board in 1979-80.

In 1980 the electronic package at remote sites consisted of a Metracom radio, produced by Secode Electronics of Dallas, TX. See photos below.


The radio measured 17x15x4 inches and weighted 13 pounds. It had a mother board, four sensor interface cards, a power control unit, two 24 ampere-hour battery packs, and a 36 volt battery pack. The radio consisted of a receiver board, transmitter board, an exciter board, a data acquisition board, and a control logic board. The power control unit contained the main power switch, and a transformer which stepped up the 12 volts from the main batteries to 36 volts for the transmit battery. The nominal forward power was 300 watts. These radios were upgraded via a new board to what was called a microprocessor/data acquisition board which gave us maximum, minimum, and average temperatures. Prior to this upgrade we had only current temperature data. We could only get one report per day and the site ID was programmed into the radio through a 40 conductor plug, which was hard wired for the octal site address. The antennas were decibel product, dual element yagi's, with a feed element which would equate to the current balun. These feed elements were not water tight and would get wet and then corrode, causing the reverse power to rise and sometimes fry the transmitter.

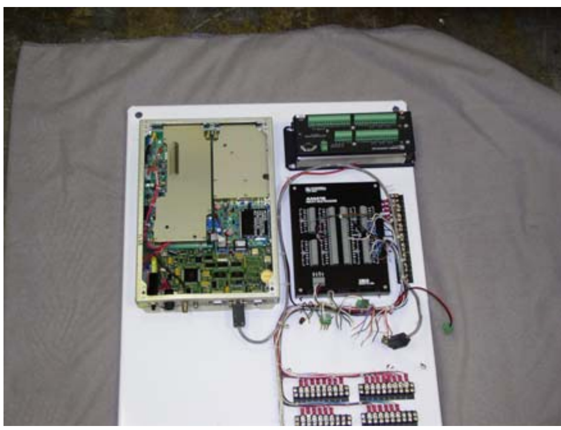
It could be said, "Timing is everything or the mother of invention is necessity". With the eruption of Mt. Saint Helens, the next generation SNOTEL radio was needed. The 550 radio was designed and produced by MCC in Kent, WA. See photos below.



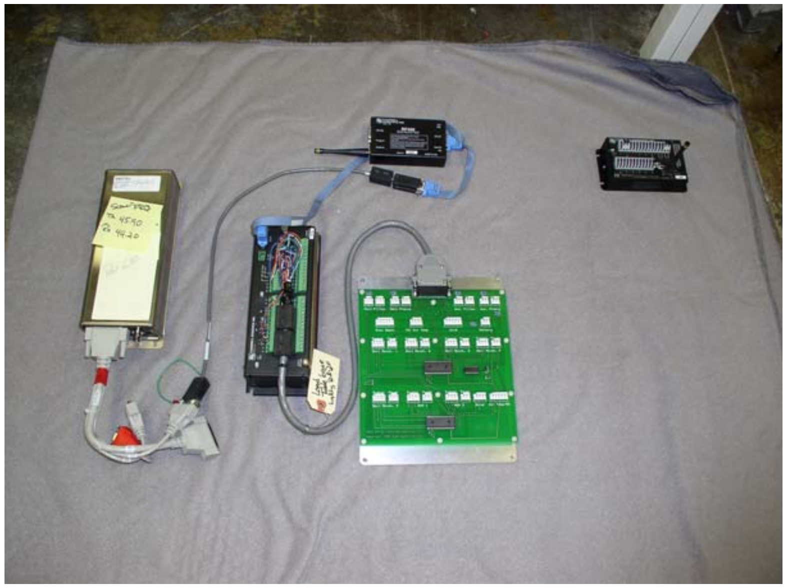

With the eruption, the National weather Service wanted special monitoring around the mountain, so they provided funds to the Soil Conservation Service to install seven sites. The sites needed to have some capabilities that the Secode radio did not have. These included rapid snow melt or snow (ash) accumulation when it's above freezing and the ability to send out an alert. The 550 series radios were designed and built during the summer of 1980 and installed around the mountain that fall. These radios measured 13x11x3 inches, weighed 8 pounds, and transmitted at 300 watts, requiring a 36 volt battery pack. We had maximum, minimum, and average temperature, and entered the site address through a series of thumb wheel switches. They could be programmed for event reporting, which was a disaster, as the transducer output varied so much during the day that there were constant events being transmitted. We still used the single or double battery packs with two 24 ampere-hour batteries in each, and a 36 volt pack.

The next generation of radios was the MCC 550A unit, with 12 volt 100 watt transmitters. They were extremely troublesome. We had data spikes (anomalies), performance problems, power problems and antenna problems. We began using Scala antennas at the same time we started using 550A radios. The data spikes we noticed were mostly on temperature sensors. We moved, re-oriented, and shielded the sensors. The power problems were associated with too many transmissions, too little solar power, with batteries that were too small. The MCC 550B was designed to clear up these problems and operated with a 12 volt battery and had 100 watts output.

A new era in SNOTEL instrumentation started in 1999 with the introduction of the MCC 545 series of radios. These would also be the precursors to the radio and sensor configuration we now use. See photos below.

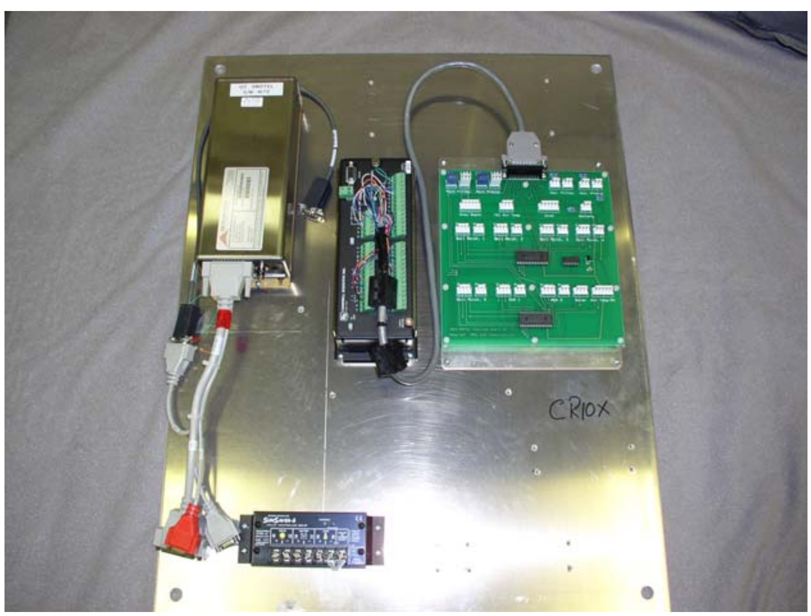



The MCC 545A measuring 14x10x2 inches and weighting 4 lbs., does not have data acquisition capability, so the need for a data logger is necessary. SNOTEL sites were becoming what is called fire weather instrumented sites. These sites have soil moisture and temperature, wind, solar radiation, relative humidly, precipitation, and snow depth sensors, along with the standard snow water equivalent and air temperature sensors. The MCC 545B was introduced in 2002 measuring 9x4x2 inches and weighting 3.5 lbs. See photo below.



The 545B has a 100 watt transmitter and RF receiver that operates on a 90 degree phase shift key which is different than the MCC 550 and 545A series. This has required the entire SNOTEL system, of nearly 800 remote sites, to be upgraded to the MCC 545B/Campbell cr10x combination, which was scheduled for completion by October 1, 2006. The sites use either a Campbell 1632 multiplexer or a Dan Judd interface board to connect the sensors to the cr10x data logger.

Another small test project is running in the Utah DCO it consists of MCC 545B, Campbell cr10x, Campbell cr205 and rf400, Judd interface board, pillow and precipitation transducers. The project has a typical SNOTEL site and a remote soil stack 2.5 miles away in another drainage, transmitting back through the SNOTEL station. The remote soils stacks consist of 10 soils probes 5 in a conifer stand and 5 in a deciduous aspen stand. The test project is in conjunction with graduate work being done at USU, Logan, Utah.



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This document is 615 pages long. It is available on the Internet: Google the title and author.

We include here only initial pages and those relevant to for SkyTel's purpose shown in comments.

ATTACHMENT 4

ITS Communications Document

Prepared by:

Lockheed Martin Federal Systems
Odetics Intelligent Transportation Systems Division

Prepared for:

Federal Highway Administration
US Department of Transportation
Washington, D. C. 20590

January 1997

SkyTel: See other SkyTel MBC douments on the Scribd MBC Collection for background of Meteor Burst Communications ("MBC").

This document is presented here to provide a summary description of conventional thinking on us of MBC for vehicle communications, including AVL, as a component of Intelligent Transportation Systems ("ITS").

See pp. 7-74 to 7-75. (See also D-5: this lists two books on Meteor Burst Communications, principally for engineers.)

A full chapter on the just stated topic can be found in the following book (since it is copyrighted and not in the public domain, SkyTel cannot republish any substantial parts on Scribd): Scott Elliot and Daniel Dailey, Wireless Communications for Intelligent Transportation Systems. Artech House, 1995. Chapter 11, pp. 260-276. SkyTel places on Scribd a brief fair-use selection of this material.

Many advances in wireless since this and most all other MBC technical and applications literature were published allow far more advanced MBC systems. These will support higher capacity and other wireless system characteristics useful for ITS mobile and fixed link purposes.

One principal MBC ITS application SkyTel plans is secure nationwide delivery of N-RTK data to both private and professional radio systems, and also to commercial wireless operators: Skybridge plans to provide this service at no profit. N-RTK augments GPS-GNSS for much higher accuracy. See the Skybridge C-HALO collection on Scribd.

SkyTel plans use of nationwide MBC for full coverage (even in most remote areas) along with radio mesh nets for high two-way communications capacity along transport routes, cities and other areas.

SkyTel has obtained over the last decade the required FCC licenses for the above-summarized ITS wireless: in 35, 43, 200 and 900 MHz bands. The same wireless systems will also support intelligent or smart energy ("smart grid"), emergency wireless, and environmental monitoring and protection ("green wireless").

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NATIONAL ITS COMMUNICATION

EXECUTIVE SUMMARY

In the last decade, many communication technologies and systems have been introduced at an ever-accelerating pace, and some are gaining wide acceptance. The complex world of telecommunications is evolving and expanding rapidly. For many application areas, including transportation, myriad communication options are available to the system architect and designer. These solutions, of course, meet the requirements at hand with varying results and implications of performance, cost, and user acceptance.

The ITS world is also broad and varied, as amply demonstrated by the tweny-nine ITS user services, their distinct needs, and their complex interactions and synergies. The National ITS Architecture can be viewed as a framework that ties together the transportation and telecommunication worlds, to enable the creation, and effective delivery, of the broad spectrum of ITS services. Throughout the Architecture effort, the emphasis has been on flexibility. This allows the local implementors and service providers to select the specific technologies, within the framework of the architecture, that best meet their needs (expressed either in terms of market realities or jurisdictional constraints). The price paid in the architecture is some added complexity. It has been critical, therefore, to espouse an architectural concept that mitigates the complexity of interconnecting many transportation systems with multiple types of communication links. The basic concept wherein the Physical Architecture has a Transportation and a Communication Layer is specifically intended to simplify the process by separating these two fairly independent domains, yet, at the same time, having them tightly coupled to meet the ITS users service requirements.

This National ITS Communication Document contains, under the same cover, the information necessary to describe and characterize all aspects of communications within the National ITS Architecture. It presents a thorough, coherent definition of the “communication layer” of the Architecture. From a National ITS Program perspective, this encompasses two broad thrusts: 1) communication architecture definition (i.e., selection of communication service and media types to interconnect the appropriate transportation systems), and 2) several types of inter-related communication analyses to ensure the feasibility and soundness of the architectural decisions made in the definition. The analyses performed comprise:

- An analysis of the data loading requirements derived from the ITS user service requirements, the Logical and Physical Architectures and their data flows, the ITS service deployment timeline, and the attributes of the candidate scenarios in the "evaluatory design".
- A wide-ranging, balanced assessment of a broad spectrum of communication technologies that are applicable to the interconnections defined in the communication layer of the Physical Architecture. The evaluation is performed from a National ITS Architecture standpoint.
- An in-depth, quantitative analysis of the real-world performance of selected technologies that are good candidates for adoption as ITS service delivery media, and for which reliable, state-of-the-art simulation tools are available. The performance is determined under the demands of the ITS and other projected applications of the media.
- A number of supporting technical and economic telecommunications analyses that address some important architecture-related issues, such as the appropriate use of dedicated short range communication (DSRC) systems.

One of the fundamental guiding philosophies in developing the National Architecture has been to leverage the existing and emerging infrastructures, both transportation and communication. This is to maximize the feasibility of the architecture, and to mitigate the risk inherent in creating and offering intelligent transportation systems, services, and products, all of which are quite new and in need of acceptance.

The communication architecture definition adopts the same philosophy. It follows, and expands upon, a rigorous, well-accepted methodology used widely in the world of telecommunications. Several wireless systems which are tied to wireline networks have used this approach. It starts from the basic network functions and building blocks and proceeds to the definition of a network reference model, which identifies the physical communication equipment (e.g., base station), to perform the required communication functions, and the interfaces between them. These interfaces are the most salient element of the model from an ITS perspective; some of these interfaces need to be standardized to ensure interoperability.

Because of the variances in the ITS user service requirements (from a communication perspective), it is clear, even from a cursory examination, that the user services do not share a common information transfer capability. Specifically, ITS user services like electronic toll collection demand communication needs that can only be met by dedicated infrastructures for technical feasibility, notwithstanding institutional, reasons. The ITS network reference model that was developed incorporates this basic extension of the models developed for commercial telecommunication networks.

In general, the Communication Architecture for ITS has two components: one wireless and one wireline. All Transportation Layer entities requiring information transfer are supported by one, or both, of these components. In many cases, the communication layer appears to the ITS user (on the transportation layer) as "communication plumbing", many details of which can, and should, remain transparent. Nevertheless, the basic telecommunication media types have critical architectural importance. The wireline portion of the network can be manifested in many different ways, most implementation dependent. The wireless portion is manifested in three basic, different ways:

- Wide-area wireless infrastructure, supporting wide-area information transfer (many data flows). For example, the direct use of existing and emerging mobile wireless systems. The wireless interface to this infrastructure is referred to as u1. It denotes a wide area wireless airlink, with one of a set of base stations providing connections to mobile or untethered users. It is typified by the current cellular telephone and data networks or the larger cells of Specialized Mobile Radio for two way communication, as well as paging and broadcast systems. A further subdivision of this interface is possible and is used here in the document: u1t denotes two-way interconnectivity; and u1b denotes one-way, broadcast-type connectivity.

- Short range wireless infrastructure for short-range information transfer (also many data flows, but limited to specific applications). This infrastructure would typically be dedicated to ITS uses. The wireless interface to this infrastructure is referred to as u2, denoting a short-range airlink used for close-proximity (typically less than 50–100 feet) transmissions between a mobile user and a base station, typified by transfers of vehicle identification numbers at toll booths.
- Dedicated wireless system handling high data rate, low probability of error, fairly short range, Automated Highway Systems related (AHS-related) data flows, such as vehicle to vehicle transceiver radio systems. This wireless interface is denoted by u3. Systems in this area are still in the early research phase.

The ITS network reference model has to be tied to the specific interconnections between the transportation systems or subsystem, e.g., connection between Information Service Provider (ISP) subsystem and a vehicle subsystem (VS). The key step is performed through the Architecture Interconnect Diagram (AID), actually, a whole collection of them of varying levels of detail. These marry the communication service requirements (which are generic information exchange capabilities such as messaging data) to the data flow requirements in the transportation layer, and specify the type of interface required (u1, u2, u3, w). The Level-0 AID is the top level diagram showing the types of interconnectivities between the various transportation subsystems, and, perhaps, is the best description of the communication framework in the ITS architecture. The AID Level-0 is broken down further to show subsets of it depicting the data flows that, say, use broadcast (u1b), or those that use either broadcast or two-way wide area wireless (u1t).

Various media and media types are applicable as possible candidates for each type of interconnection. The best communication technology family applicable to each data flow is specified. This still remains above the level of identifying a specific technology or system. In practice, i.e., in a real-world ITS deployment, the final step of selecting a given technology would be performed by the local ITS implementor or service provider. A proffered specification here would clearly transcend the boundaries of architecture and into the realm of system design. It is therefore avoided to the extent possible in the communication architecture definition phase.

To assist the implementors and service providers in the ITS community, a broad technology assessment is performed. It attempts to use as much factual information as is available to identify and compare key pertinent attributes of the different communication technologies from a National ITS perspective. This, at least, facilitates the identification of which technologies are suitable for the implementations of what data flows.

A host of land-mobile (i.e., cellular, SMR, paging, etc.), FM broadcast, satellite, and short range communication systems have been assessed. The assessment addresses the maturity of the candidate technologies and analyzes their capability for supporting ITS in general, and the architecture in particular. Within the limits of reliable publicly available information, the following attributes are assessed: infrastructure and/or service cost as applicable, terminal cost, coverage, and deployment time-line (if not yet deployed). Furthermore, interface issues (i.e., open versus proprietary) are also addressed from a national ITS perspective. Whenever possible, analysis is performed to determine: 1) system capacity, i.e., supported information rate, 2) delay throughput, 3) mobility constraints, etc. The ITS Architecture data flow specifications are used in the analysis, including message sizes and update frequencies. The key comparison characteristics are finally summarized in tables.

Another area focus in this document is ITS communication performance evaluation. The objective is to determine whether the National ITS Architecture is feasible, from the standpoint that communication technologies exist and will continue to evolve to meet its demands, both technically and cost effectively. To set the stage for this, data loading analyses have been completed for the wide area wireless interfaces u1t, u1b, and the wireline interface w-- data loading for the u2 and u3 interfaces is not as useful, so link data rates have been determined instead.

The data loading analyses define all of the messages that flow between all of the physical subsystems. Deployment information from the evolutionary deployment strategy has been used to define which services, and therefore which messages would be available for each of the scenario and time frames specified by the Government. The three scenarios provided are addressed, namely, Urbansville (based on Detroit), Thruville (an inter-urban corridor in NJ/PA), and Mountainville (a rugged rural setting based on Lincoln County, Montana).

Seven user service groups with distinct usage patterns have been defined, along with the frequency of use of the messages by each user group. Messages have been assigned to the u1t, u1b, and w interfaces based on suitability, and are allowed to flow over multiple interfaces with a fraction assigned to each one. The resulting data loading analyses provide the data loads and a complete description of the message statistics, on all of the above interfaces and links. These data are used to drive the communications simulations.

For the u1t interface (two way wide area wireless), the data loading results indicate that for Urbansville in 2002 the largest data loads result from the CVO-local user service group, followed closely by transit and private vehicles. In Thruville, for the same time period, CVO-local and transit are alone the largest data users. For Urbansville in 2012, private vehicle and CVO-local are the largest data users, at about twice the rate of transit, with the others far below. For Thruville in 2012, CVO-local remains the largest data user, followed by transit. The Mountainville data loads are very low, with CVO-local the largest user, followed by private vehicles.

In each of the u1t scenarios and time frames studied the forward direction data load (center to vehicle) is always higher than the reverse direction load, by a factor of two to three. The consistent users of the reverse direction are CVO and transit.

The ITS Architecture data loading results have been used as input to the communication simulations. Due to the relative scarcity of wireless communications (relative to wireline), emphasis has been placed on the evaluation of wireless system performance. However, network end-to-end performance, comprising both the wireless and wireline components, given in terms of delay and throughput, is also obtained. Furthermore, representative analyses of wireline networks have also been included.

The wireless simulations performed were for Cellular Digital Packet Data (CDPD), primarily because it is an open standard with a publicly available specification, and because validated, state-of-the-art simulations were made available for use on the ITS Architecture Program. These simulations accurately reflect the mobile system conditions experienced in the real world, including variable propagation characteristics, land use/land cover, user profiles, and interference among different system users (voice and data). The simulations also handle the instantaneous fluctuations and random behavior in the data loads whose peak period averages are derived in the data loading anlysis sections. The simulation modeling tools have been tested and validated in the deployment and engineering of commercial wireless networks by GTE.

Simulations have been run for the three scenarios provided by the Government. Since the number of users is very small in Mountainville, only cellular coverage was obtained to ascertain its adequacy in that remote area. For both Urbansville and Thruville, scenarios with both ITS and Non-ITS data traffic projected for the CDPD network were run, under normal peak conditions and in the presence of a major transportation incident.

The Government-provided scenario information was substantially augmented with information on actual cellular system deployment obtained directly from FCC filings. A minor amount of radio engineering was performed to fill a few gaps in the information obtained. The commercial wireless deployment assumed in the simulation runs, therefore, is very representative of the real operational systems. In fact, because of the continuous and rapid expansion of these systems, the results of the simulations are worst case in nature.

The wireless simulation results have shown that the reverse link delay (the data sent from the vehicle to the infrastructure), even in presence of non-ITS data, and in the case of an incident during the peak period, is very low (150 ms for ITS only; 300 ms for ITS plus non-ITS; with a 10% increase in the sectors affected by the incident).

The results of the CDPD simulations are further validated by the results of an operational field trial that was performed in the spring of 1995, jointly by GTE and Rockwell, in the San Francisco Bay Area. The application demonstrated was commercial fleet management (dispatch), using GPS location, and CDPD as an operational commercial wireless network. A synopsis of the trial and its results are presented in an Appendix.

The above results for CDPD should be interpreted as a “proof by example”. A commercial wireless data network is available today to meet the projected ITS requirements. Other networks also exist, and can be used, as indicated in the technology assessment sections. Future wireless data networks, and commercial wireless networks in general, will be even more capable.

The simulation results for the wireline network example deployment indicate that extremely small and completely insignificant delays are encountered, when the system is designed to be adequate for the projected use. With the capacities achievable today with fiber, whether leased or owned, wireline performance adequacy is not really an issue. The key issues there pertain to the costs of installation versus sustained operation for any given ITS deployment scenario.

The overarching conclusion from the communication system performance analyses is that commercially available wide area wireless and wireline infrastructures and services adequately meet the requirements of the ITS architecture in those areas. These systems easily meet the projected ITS data loads into the foreseeable future, and through natural market pull, their continued expansion will meet any future ITS growth. Hence, from that particular standpoint, the National ITS Architecture is indeed sound and feasible.

This National ITS Communication document also contains additional analyses to support some of the architectural decisions taken during the course of the project, and reflected in the architecture definition. One such decision is avoiding the use of dedicated beacon systems for wide area applications, such as traveler information, route guidance, mayday an so on. The technical and economic drivers are addressed in an appendix and synopsized in the technology assessment section.

any optimistic expectations about service availability, given the huge investments required by most of the proposed systems in the face of market uncertainties, as well as their complexity and deployment risk.

7.5.1.1.4 Meteor Burst Communications

The meteor burst (or meteor scatter) channel, known as the "poor man's satellite channel", relies on the ionized trails of meteors as reflectors to achieve long range packet data communications. It was found that useful ionized meteor trails occur at an altitude of about 80-120 km above the earth's surface. Trails with useful electron densities for reflecting radio signals in the range of 40 to 50 MHz were found to be plentiful enough to provide communications over a range of roughly 2000 km. The minimum range limitation was found to be 400 km, as determined by the scattering geometry and electron density. The intermittent nature of the channel has to do with the random distribution of the meteors of interest which shows a strong diurnal variation (peaking at 6:00 local time, and with a distinct minimum at 18:00), and follows the Poisson law. Ionized trails were found to have a lifetime of only a few tenths of a second, creating the need for rapid exchange of information (thus the term "burst communications"). Due to the unique characteristics of the propagation mechanism (see Figures 7.5-23 and 7.5-24), Meteor Burst Communications relies on an inherent spatial multiplexing to reduce the contention in a network with potentially more than ten thousand units.

SkyTel:

- An unlimited number of vehicles and other animate things can be sent N-RTK and other ITS-critical data in one-way downlinks mode (like GPS).

- MBC can also provide substantial uplink capacity by viable means not covered in this simple analysis: each MBC link is for a relatively small spot on the earth, providing high spectrum reuse efficiency --

- Also, use of many base stations, relay stations, channels, and more advanced wireless protocols and other tech, will greatly increase both downlink throughput capacity and reverse (or up) link capacity.

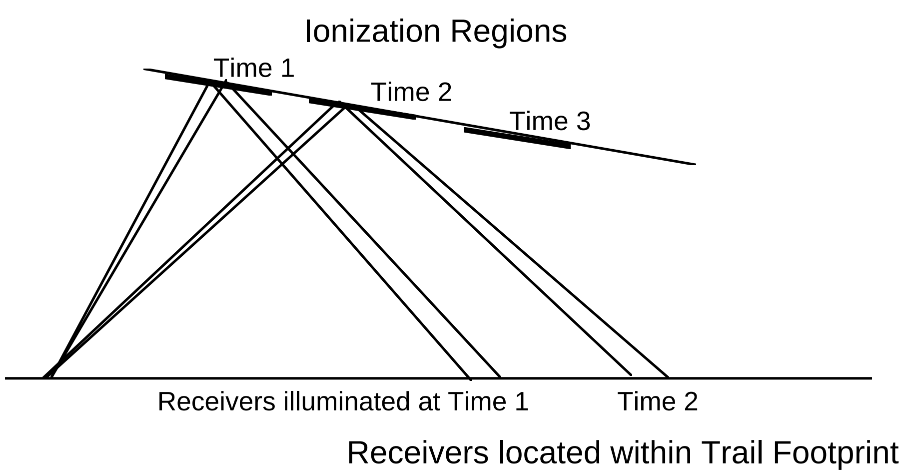


Figure 7.5-23 Motion of Ground Illumination Region due to Trail Formation and Decay

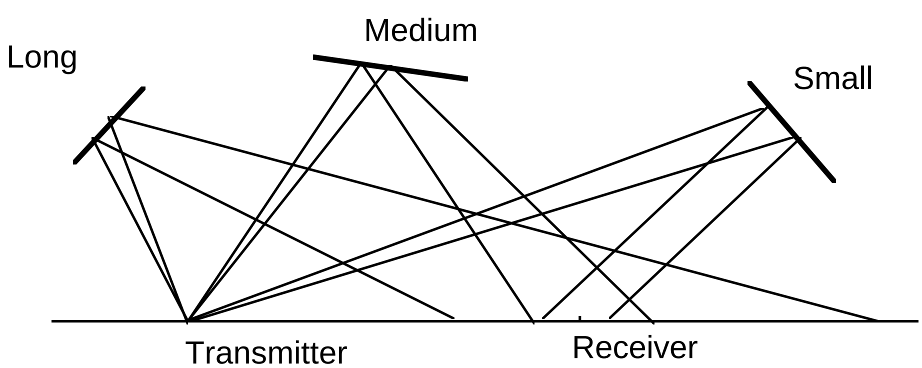


Figure 7.5-24 Effect of Trail Location on Size of Footprint

Skytel:

This is good thinking at the time, and still substantially correct. But MBC can provide far more, at this time, at least if planned and implemented as

- SkyTel is pursuing. N-RTK can be delivered far more frequently than needed for vehicles even at high speeds by MBC, to all vehicles.

- Reverse-link reporting back can be as often as useful, far more often than indicated here: in the seconds range for the few applications and situations calling for that, with combination of MBC super-wide area coverage plus regional and local mesh net coverage working off of MBC fixed-site Relay Stations, as SkyTel Plans.

- These mesh nets will use mostly 200 and 900 MHz, but some DSRC 5.9 GHz also, as well as a modest amount of 35 and 43 MHz. Vehicles can support SDR multi-band, multi-protocol radios.

A system with the characteristics described above seems appropriate for communicating with remote, usually rural, sparsely populated areas, when there is no need for immediate, urgent communications. The coverage of conventional UHF cellular systems is too small for cost effective seamless coverage in very rural areas, especially away from major interstate highways. On the other hand, satellite service is very expensive to install and operate. Meteor Burst technology costs approximately 1/5 that of satellite systems, and the long term life cycle costs savings can not be underestimated (meteors are in essence free natural satellites, always available). Furthermore, since Meteor Burst operates in the low VHF band, the cost of the vehicle radio equipment is approximately half that of corresponding satellite equipment.

Skytel:

Low VHF band radios have or can have certain tech simplicity and cost savings vs higher-frequency radios, especially advanced digital radios: less expensive conversion between analog and digital and base to RF bands, etc.

Examples of ITS services that a Meteor Burst system could potentially support are wide area Automatic Vehicle Location (AVL), and remote (long haul) Fleet Management. Surveys of potential users indicate that when out on the open road, position information every 10 to 15 minutes with short message capabilities is adequate for significant productivity enhancement. A Meteor Burst tracking system can fill the gap in the conventional cellular system where in remote areas the density of vehicles (and fixed users) cannot justify the base station infrastructure.

A Meteor Burst system could provide seamless coverage of the continental U.S. with as few as 100 base stations. However, noise levels in urban areas are too high for Meteor Burst usage. There, cellular coverage would have to be considered, pointing to the possibility of dual MB-cellular systems.

Several Meteor Burst systems have already been installed and proven effective:

- In the 1950's, Canada installed the JANET system between Toronto and Port Arthur for simple point to point teletype communications.
- Also in the 1950's, SRI, under contract from the U.S. Air Force, operated a test link from Palo Alto, CA to Bozeman, Montana, primarily for propagation research.
- The 60's saw the first operational military MB communication system deployed in Europe, called COMET, operated by the NATO SHAPE technical center, providing communication from The Hague, Netherlands, to southern France, again to transmit conventional teletype messages.
- In the late 70's, the Alaska SNOTEL (for SNOwpack TELemetry) system was installed to provide meteorological information from remote locations throughout Alaska.

DOA's SNOTEL+ SCAN is now largely nationwide

- The Alaska National Guard recently installed a MB system that ties headquarters to remote locations throughout the state.
- A MB system has been installed between Sondstrom AB and Thole AB, Greenland.
- MB was selected for the Small Mobile ICBM (SICBM) program to provide primary communication under almost all conditions between mobile launch control centers and up to 1000 mobile launchers randomly dispersed over a wide area.
- Currently NORAD is testing a C^3 MB network that will connect the continental US, Alaska, and Canada.

As for commercial systems, a few experiments have been successful, namely one in the Portland, OR area where a long haul Fleet Management system has been deployed, taking advantage of the MB beyond line of sight communication capabilities.

As a conclusion, MB, although requiring a dedicated system, seems to be a cheap but still effective alternative to expensive satellite systems. In any circumstance, it cannot provide overall seamless coverage, thus requiring terrestrial cell-based coverage in urban and suburban areas in a dual MB-cellular system configuration.

The limitations do not seem this great: recent spectrum-use surveys has shown, these days, very-low 35-45 MHz band activity (and total noise) in uban-suburban areas (or rural areas).

In addition, the N-RTK and other ITS-critical one-way data can be easily provided nationwide by MBC (to MBC fixed stations) to commercial wireless networks, as well as government, professional, and private wireless networks for their distribution. This will provide alternative and redundant delivery to the SkyTel MBC+Mesh networks.

D.1.4 Meteor Burst Systems

Main sources:

1. *Meteor Burst Communications - Theory and Practice*, D.L. Schilling, Ed., John Wiley & Sons, 1993
2. *Meteor Burst Communications*, J.Z. Schanker, Artech House, 1990

D.1.5 Broadcast Systems

An interesting article appeared recently in the IEEE Spectrum Magazine, covering most aspects of digital broadcasting:

1. "Broadcasting with Digital Audio", Robert Braham, Ed., IEEE Spectrum, March 1996

D.1.5.1 FM Subcarrier

Similar pages exist for other cities in the country:

City	URL
San Diego, CA	http://www.scubed.com/caltrans/sd/big_map.shtml
Los Angeles, CA	http://www.scubed.com/caltrans/la/la_big_map.shtml
Seattle, WA	http://www.wsdot.wa.gov/regions/northwest/NWFLOW/
Houston, TX	http://herman.tamu.edu/traffic.html
Chicago, IL	http://www.ai.eecs.uic.edu/GCM/CongestionMap.html

D.1.5.2 DAB

Company	URL
EuroDAB Newsletter	http://www.ebu.ch/dep_tech/eurodab.html
Digital Radio Research Inc. (DRRI)	http://radioworks.cbc.ca/radio/digital-radio/drri.html
USA Digital Radio	http://www.usadr.com/techieam.html

D.1.6 Short-Range Communications

ITS America's World Wide Web site, **http://www.itsa.org/** is the main source of short-range communications information, since it maintains a data base of all related information.

D.1.6.1 DSRC Communications

Company	Home Page
Hughes	http://www.hughes.com/

These pages are in the public domain, downloadable from the Internet.

ATTACHMENT 5

NCHRP Web Document 2

(Project 3-51)

Appendix A of Contractor's Final Report

SkyTel republishes the following excerpt regarding use of:

(1) Multilateration LMS (M-LMS) FCC licenses (in the 902-928 MHz licensed band) for Intelligent Transportation Systems (ITS) wireless, and

(2) Meteor Burst Communications (MBC) for ITS Wireless.

As we discuss in other papers in our Scrib collection Folder on MBC: prior to our current common-sense expansion of MBC using modern technology and a large number of Master and Relay stations (but still, orders of magnitute less that the fixed sites needed for traditional terrestrial wireless wide-area systems with similar total coverage), MBC had and is desribed in reports like this as having certain apparently unsolvable limitations in wait time between useable links, and throughput.

With our plan and current technology, these can be vastly improved.

Thus, the value of MBC to ITS will be vastly improved.

Communication Mediums for Intelligent Transportation Systems

Final Report

Prepared for

National Cooperative Highway Research Program
Transportation Research Board
National Research Council

by

Kimley-Horn and Associates, Inc.
Dallas, Texas

Bruce C. Abernathy, P.E., Ph.D., Principal Investigator
James E. Gunn, P.E., Ph.D., Asst. Principal Investigator
Joyce E. Minor, Editor

June 1996

FOREWORD

This report describes many of the alternatives available in designing the communications subsystem of an intelligent transportation system (ITS). The various communication mediums, protocols, and terminals are extensively discussed. A rational approach to communication subsystem design is introduced along with examples of typical systems and information on cost estimating and support considerations. Lastly, perceived barriers to implementation of advanced communication technologies are discussed as well as strategies to overcome them. This report will be extremely useful to those designing a communications system or overseeing the design of one.

In January 1996, Secretary of Transportation Federico Peña introduced a major new Department of Transportation initiative called "Operation TimeSaver." The goal of Operation Timesaver is to install Intelligent Transportation Infrastructure (ITI) in 75 of the largest U.S. metropolitan areas in 10 years. The ITI, as defined by the U.S. DOT, consists of the following nine elements: smart traffic-control systems, freeway management systems, transit management systems, incident management programs, electronic toll collection on roads and bridges, electronic fare payment, railroad grade crossings that are integrated into the overall system, emergency response providers, and traveler information systems. The ITI subsumes the more traditional elements of ITS.

The cost of an ITS is driven by the communication subsystem, which often accounts for 50 percent of the budget. The communications industry is rapidly evolving, creating technologies that can beneficially be applied to ITS. This requires transportation agencies to continually reassess their standards because last year's design may not be the best given today's conditions.

Many transportation agencies lack the in-house talent to design communications systems and rely upon the work of consultants. An understanding of communications concepts and capabilities is needed to both scope the work of the consultant and to critically review the consultant's products.

The objectives of NCHRP Project 3-51 were to assess advanced communication mediums applicable to ITS and provide guidance on selection, design, deployment, maintenance, and staffing for these mediums. Kimley-Horn and Associates, assisted by the voluntary cooperation of many communications suppliers, has developed a thorough guide to communications that will be extremely helpful both to those designing communications systems and those responsible for overseeing the work of consultants.

Appendix A of the report, included in this volume, is the primary user guide resulting from the project. It is available for viewing on the world-wide web and copies are available for sale from TRB. Appendices B (Presentation Material), C (Medium/Terminal Data Sheets), and D (Annotative Bibliography of Communications Technology) are available as downloadable files on the world-wide web. The world-wide web documents are available on the page describing NCHRP Project 3-51 on the TRB Cooperative Research Program homepage, http://www2.nas.edu/trbcrp.

SkyTel Note. This was written before the current technologies that will allow wireless "Cooperative High Accuracy Location" or "C-HALO"-- sub-foot to sub-meter accuracy location of vehicles (and other moving thigs). C-HALO will enable the below and other more advanced ITS applications. The core reason for accidents and congestion is simple: without C-HALO inmplemented, vehicles cannot very safety, reliably and efficiently move along roadways (or waterways and other travel ways), but with it they will be able to do so. See our HALO- STEER folder on Scrid.

A.0 Introduction

The Intelligent Transportation Systems (ITS) goal is to increase the efficiency of the nation's transportation infrastructure by:

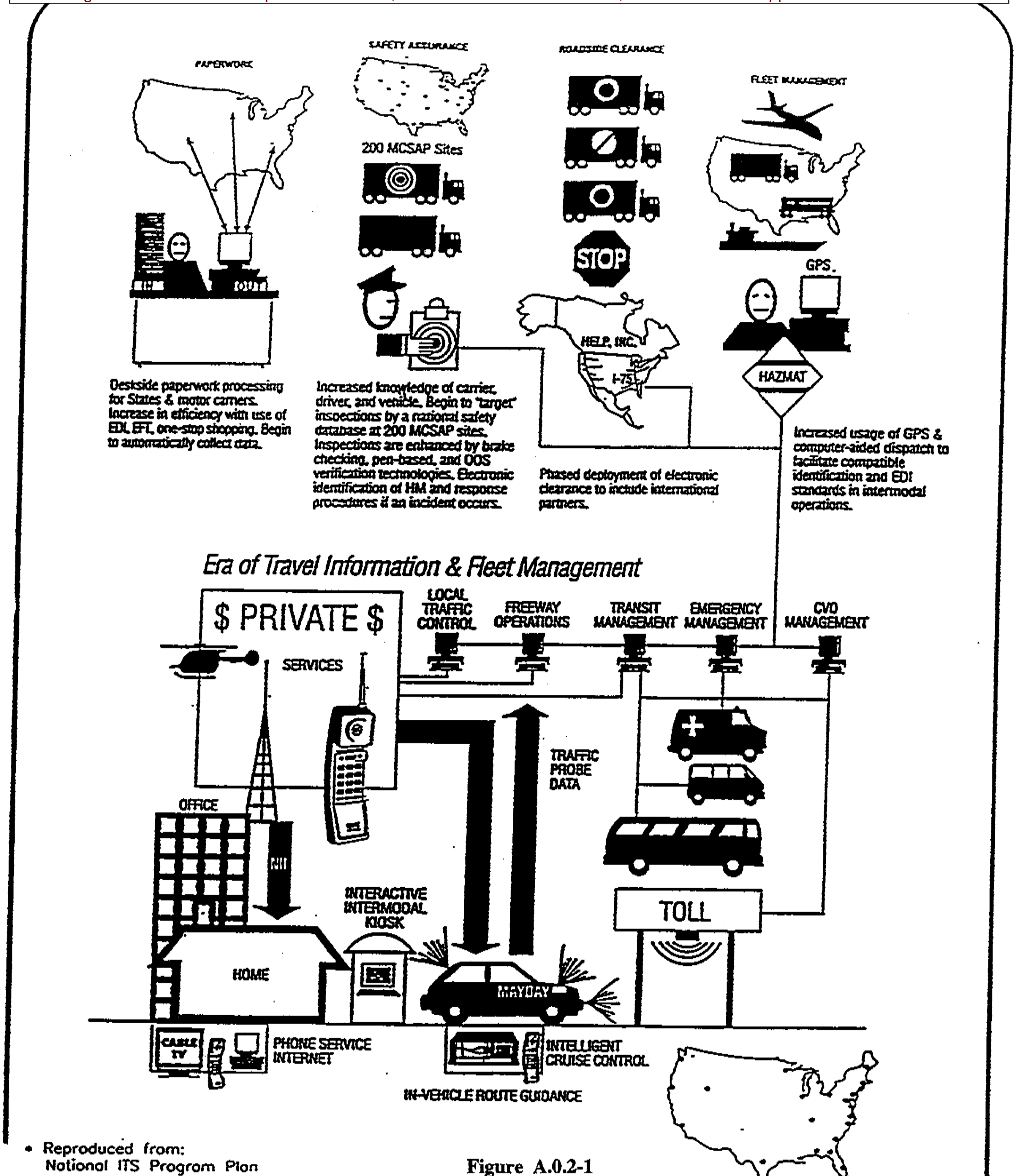
- Using sensors to measure the ongoing operations and to collect historical statistics, including the use of CCTV cameras for surveillance.
- Installing signal systems and Freeway Management Systems (FMS)to control the flow of traffic, including integration of multiple, local, regional, and national jurisdictional systems into regional systems.
- Integrating modes of travel including transit, air, and rail.
- Developing the fleet management function for CVO, transit, etc.
- Fusing data into "one-stop" Advance Traveler Information Systems (ATIS) to provide travelers with reliable, useful information for making travel decisions.

A key element in achieving these goals is the communication of travel-related data from/to field devices, to/from various public or private service providers, and to/from the public. Communication subsystems for these functions often represent 50% of the total system cost, as illustrated in **Figure A.0-1**, which details costs for several example signal systems.

Transportation planners and managers need to understand communication systems and how to cost-effectively integrate these into their operations and systems.

The communication industry is "high tech" and is experiencing rapid evolution that includes digital television, significant new wireless products and services, and high capacity fiber technologies. We will assume a digital communication network as this is the modern trend that industry is increasingly evolving toward. Digital networks are supported by the most cost-effective components, equipment, systems, and services and this trend will accelerate in the future.

Skytel: Most of these ITS applications require ITS wireless. They have not progressed nearly as fast and fully as they should have in large part since the dedicated wireless spectrum, and related approriate tech and systems, have not to date been in place. SkyTel is addressing that. 5.9 GHz DSRC spectrum is useful, but is not sutiable for the core, wide-area mobile applicatinos of ITS.

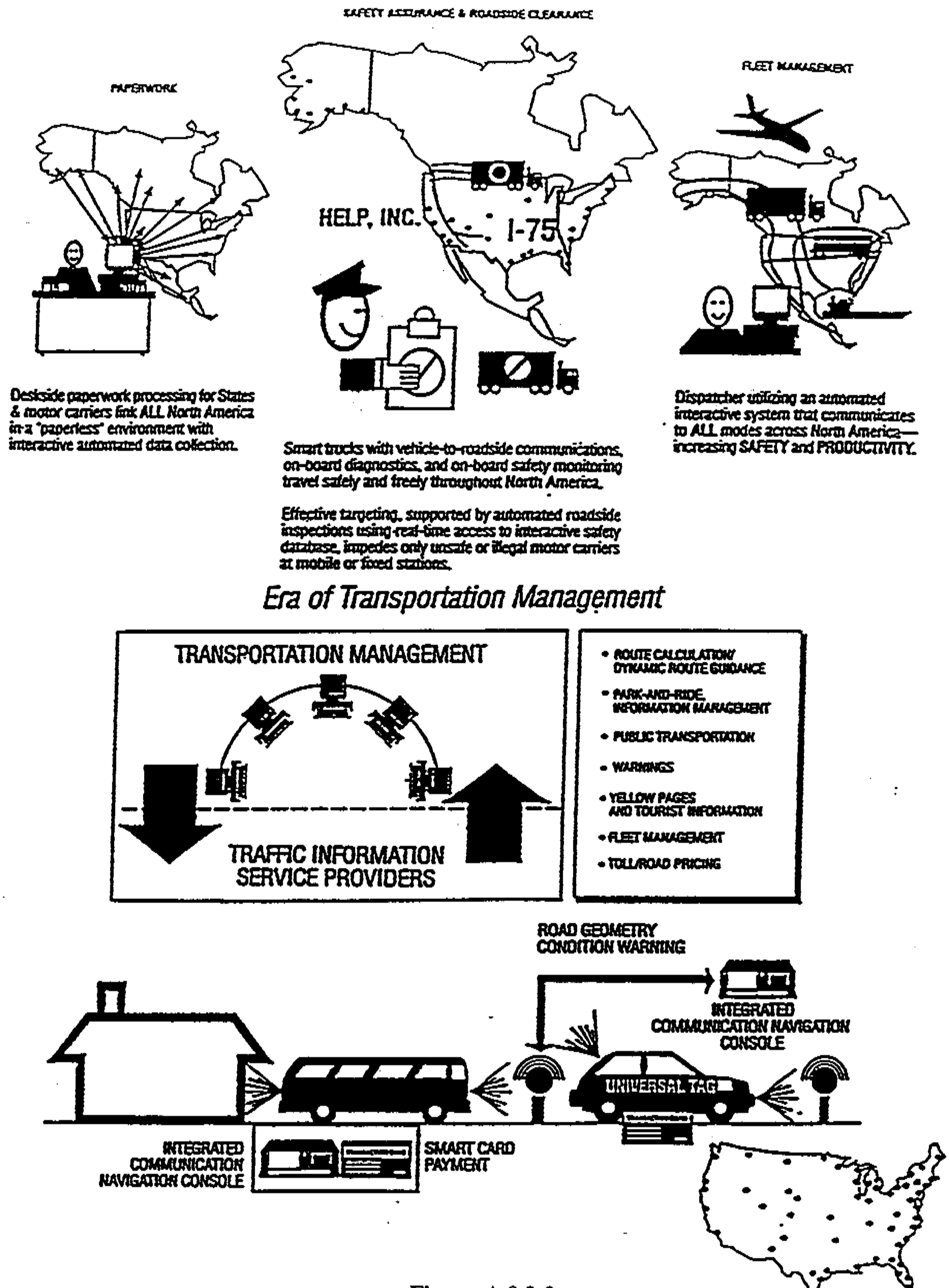


• Reproduced from:
Notional ITS Program Plan

Figure A.0.2-1

5 - Year Deployment Vision

Skytel: (Same comment as on preceding page:) Most of these ITS applications require ITS wireless. They have not progressed nearly as fast and fully as they should have in large part since the dedicated wireless spectrum, and related approriate tech and systems, have not to date been in place. SkyTel is addressing that. 5.9 GHz DSRC spectrum is useful, but is not sutiable for the core, wide-area mobile applicatinos of ITS.



* Reproduced from: Notional ITS Program Plan

Figure A.0.2-2

10 - Year Deployment Vision

SkyTel Note. (This is the same comment as on p. 2 above.) This was written before the current technologies that will allow wireless "Cooperative High Accuracy Location" or "C-HALO"-- sub-foot to sub-meter accuracy location of vehicles (and other moving thigs). C-HALO will enable the below and other more advanced ITS applications. The core reason for accidents and congestion is simple: without C-HALO inmplemented, vehicles cannot very safety, reliably and efficiently move along roadways (or waterways and other travel ways), but with it they will be able to do so. See our HALO- STEER folder on Scrid.

A.1.3 Wireless Communication

Also, one-way broadcast wireless is critical for cost-effective and spectrum-efficient delivery of much of the data needed for ITS wireless stored in telematics computer/ communication/ devices on board.

SkyTel has the FCC licensed spectrum for this form of wireless, also.

Wireless communication has significant ITS applications:

1. Any vehicle-to-infrastructure communication (i.e., mobile applications)
2. Temporary communication facilities including rapid deployment when required
3. Locations where wire or fiber are not options:
   a. canyon, river, other geographic obstacles
   b. Business or traffic disruptions for installation are unacceptable
4. Situations where more cost effective than wire or fiber
5. Diversity/hot-standby for reliability

Wireless offers bandwidths and bit rate capabilities comparable to wire and, to a lesser extent, to fiber. Various wireless options are available to support virtually any ITS link, including low-speed local links, high-speed backbones, and TOC-to-TOC links.

Wireless communication has unique characteristics compared with wire and fiber:

1. Wireless communication requires installation of only terminal equipment. In addition, up to the repeaterless propagation limits of the installation, has fixed (constant) cost per link regardless of distance, compared with fiber/wire which must include approximate linear cost/unit of distance. This comparison is depicted in **Figure A.1.3-1**. Right-of-way/site acquisition costs are only incurred at terminal locations, not between as with fiber/wire.

2. Wireless requires FCC licensing for guaranteed interference-free operation or careful design/operation considerations in the unlicensed bands.

Skytel: This is now called the "**Location and Monitoring Service**." It is the nation's only dedicated wide-area ITS radio service (M-LMS is wide area, and N-MLS is local, but can support M-LMS for certain wide-area uses.

A.1.3.5.2 Transportation Infrastructure Radio Service (TIRS) — AVM/LMS

In February, 1995, the FCC adopted rules (FCC 95-41, February 5, 1995) for Automatic Vehicle Monitoring (AVM) under a new Subpart M starting at Part 90.350. These new rules replace interim (1970) AVM rules in 90.239 (deleted). The title of Subpart M is "Transportation Infrastructure Radio Service" (TIRS) and is intended to allow new radio-based technologies for ITS applications. The AVM name is changed to Location and Monitoring Service (LMS) and is the first radio-based technology service under this subpart.

The LMS will share spectrum in the 902-928 MHz band with other users (see **Table A.1.3.4-1**). The FCC 95-41 Report and Order (R&O) modifies and eliminates outdated regulations that have not kept pace with technological evolution that is supportive of ITS applications. The key elements of the R&O are as follows:

- Defined two general categories of LMS technologies multilateration, or wideband including direct sequence spread spectrum, and non-multilateration, or narrowband. The subbands and bandwidths are in **Table A.1.3.5.2-1.**

Table A.1.3.5.2-1

LMS Frequency Subbands

Subband (MHz)	System License	Bandwidths (MHz)	Power (Watts)
902.00 - 904.00	Non-multilateration	2.00 MHz	30
904.00 - 909.75	Multilateration	5.75 MHz	30
909.75 - 921.75	Non-multilateration	12.00 MHz	30
919.75 - 921.75	Both (shared equally)	2.00 MHz	30
921.75 - 927.25	Multilateration	5.75 MHz	30
927.25 - 928.00	Multilateration	(Forward links, 250 KHZ)	300

Skytel: This is the M-LMS "A-block." SkyTel (Skybridge & Telesaurus) hold this in over 80% of the US.

- Permit multilateration LMS systems to locate any object (i.e., vehicle or not).

- In addition to locations and monitoring information, permit LMS systems to transmit about a mobile unit, status and instructional information including voice and non-voice. Under certain conditions related to public safety or special emergency radio service, LMS systems may interconnect with the Public Switched Network (PSN).

- Expand LMS license eligibility to all entities eligible under Part 90 and to allow licensees, under qualifying criteria, to provide commercial service to paying subscribers. Establish exclusive license for multilateration systems in Major Trading Areas (MTAs) through competitive bidding, but provide a mechanism for existing operators to godfather current licenses.

- License non-multilateration systems on a shared basis in designated subbands.

- Clarify what constitutes harmful interference from Part 15 device and amateur operations as defined in Part 90.361. (Basically, indoor operations and operations with low antenna heights will not be considered harmful interference.)

- Make provisions for further testing of multilateration systems to ensure that interference to the existing, widely deployed, and expanding Part 15, unlicensed operation is minimized.

These rules have been defined to accommodate various LMS services from multiple vendors.

The multilateration, or wideband, licenses will support vehicle location using a broad band signal. Technically, a wideband signal can be received with better time resolution

$$(Time\ \ Resolution\ \approx \frac{1}{Bandwidth})$$

that can employ several techniques to accurately locate a signal source, typically a vehicle. Pulse ranging techniques are typically employed. Thus, LMS services will be available for:

SkyTel: current accuracy that can be achieved by various techinuqes using M-LMS (with GPS-GNSS, etc.) is in the sub-foot to sub-meter range reliably. See "C-HALO" comments herein.

- Vehicle location within approximately 50-200 feet depending on infrastructure and interviewing terrain/obstacles;

- Bit rates for voice/data from 1200 bps to in excess of 400,000 bps; and

SkyTel:

Two of the SkyTel entities, Skybridge Spectrum Foundation and Telesaurus Holdings GB LLC, hold the M-LMS A-Block (6 MHz total) licenses in over 80% of the US.

SkyTel entities also hold the only major collection nationwide (or in any regoin) of licensed spectrum suitable for regional and nationwide Meteor Burst Communications ("MBC"), also especially useful for ITS wireless. This is briefly discussed in this report, also.

Expansion of the scope and performance of MBC by SkyTel is noted on the last page below.

- If voice is not supported, packet technology can be employed and packet size can be tailored for short, efficient, location messages.

Unlike GPS band location systems, these multilateration services can offer two-way and other communication and integrated fleet management, emergency, vehicle security, smart/probe, communication services. These LMS services should not be as susceptible as satellite to shadowing/facing in urban areas. Additionally, LMS services ability to integrate location and communication services should prove cost-effective when available.

Core ITS applications for safety and efficiency should all be non-profit, including by use of M-LMS, and N-LMS. SkyTel is commited to his, and has made legal arrangements to secure this.

The non-multilateration cards, essentially narrowband, are intended for non-commercial applications and shared spectrum usage. Toll/RF tags are the best examples. Many of these applications can be implemented under the Part 15 unlicensed rules, but can increase power and achieve some interference protection benefits by licensing under Part 90.

It should be emphasized that Part 90 LMS operations in 902-928 MHz band have primary status and Part 15, unlicensed, operation has secondary status. Thus, in the event of interference, Part 15 applications must cease operation or change installation or configuration to eliminate interference.

A.1.3.5.3 Meteor Burst Communications

In the 1930s, researchers observed that ionized trails of meteors entering the earth's atmosphere will reflect radio waves. In the 1940s and 1950s, much research was conducted on meteor burst propagation characteristics. In the 1950s and 1960s, as satellite technology emerged for "beyond line-of-sight" communication, interest in meteor burst communication waved. Nevertheless, meteor burst communication has achieved cost effective application primarily in government sponsored remote sensor data collection. The U.S. Forestry Service has placed snow/weather sensors on remote western mountaintops to measure snow depths and melting to predict spring river/creek flow. This "SNOTEL" program uses meteor burst communication from remote mountaintop sites to communication hubs. The military uses it as a backup to potentially vulnerable satellite long range links. Meteor burst technology is also employed for truck fleet management applications.

SkyTel:

Currently, US DOA's SNOTEL and SCAN, each MBC systems, cover the vast majority of the US. DOA is in the process of obtaning a new generation of MBC equipment.

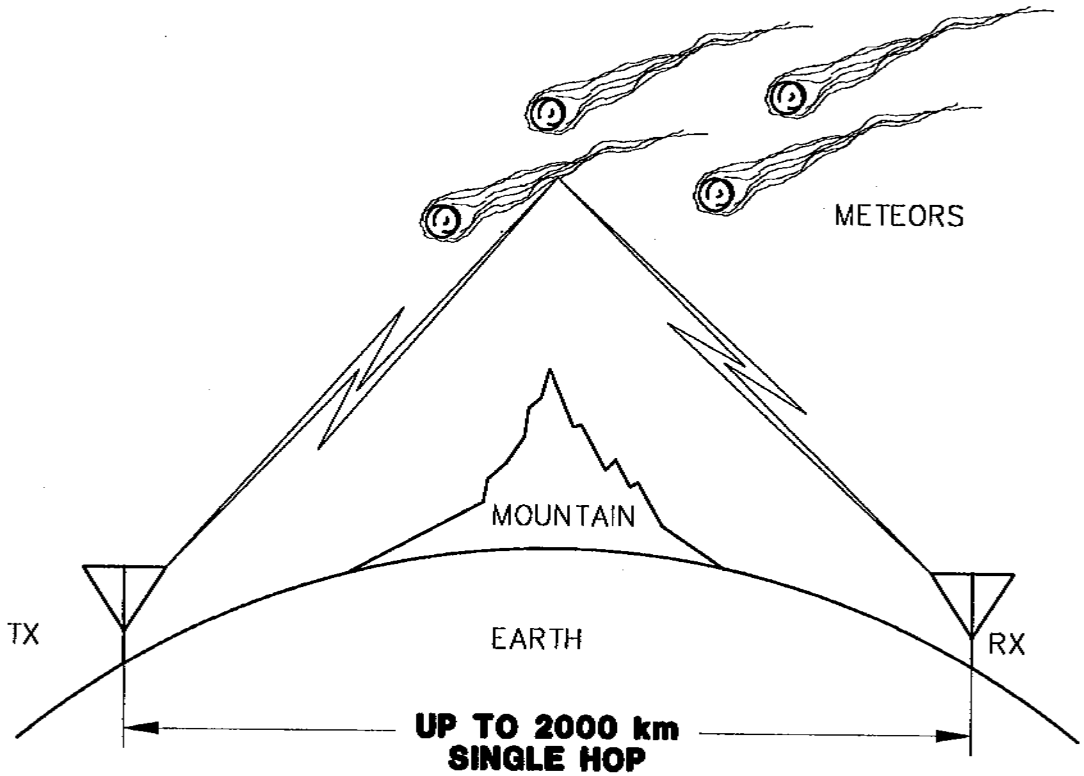
SkyTel may coordinate certain aspects of MBC with DOA, including for High Accuracy Location, includng for precision agriculture, and other natural resource- based industries in DOA's domain. This will also advance MBC for ITS.

A core goal of SkyTel is nonprofit wireless for environmental (natural resource) monitorig and protection. This fits with DOA goals. MBC is ideal for this.

The meteor burst communication channel phenomenon is illustrated in **Figure A.1.3.5.3-1**. When a meteor trail sweeps into the earth's atmosphere and is properly oriented, the transmit signal is reflected to the receiver for as long as the trail persists. The occurrence of a properly oriented trail is a statistical phenomenon in both start time, total time of occurrence, and channel characteristics. This statistical nature makes meteor burst communication unsuited for tight real-time applications. **Table A.1.3.5.3-1** illustrates typical parameters for meteor burst communication channels. The ITS applications for meteor burst focus on rural locations where data sources and destinations can be sparsely located over an extended geographical area. The specific applications include:

- Automated weather stations;
- VMS;
- Non-real-time control data such as timing plans;
- Kiosk database updates (not remotely interactive);
- Non-real-time sensor data (monitored, but not control); and
- Fleet management (e.g., CVO, transit).

SkyTel: There are many other applications with more advanced MBC as SkyTel plans.



METEOR BURST COMMUNICATIONS CHANNEL PHENOMENON

FIGURE A.1.3.5.3-1

SkyTel: MBC links can be one- or two-way.
Links to vehicles are possible with high power mobile tranceivers and appropraite cicular MBC-specific antennas.

SkyTel: Actually, extensive documented evidence shows that the best spectrum range is 35-45 MHz. SkyTel has 35 and 43 MHz.

In addition, the two bands pemit certain high accuracy time synchronization and related location determination methods.

Table A.1.3.5.3-1

Typical Meteor Burst Communication Parameters

Parameter	Value
Coverage Distance	2000 km (1250 miles - maximum)
Carrier Frequency	40 - 100 MHz
Transmit Power	200 - 2999 Watt
Bandwidth	100 kHz
Typical Bit Rates	1200 - 19,200 bps(intermittent)
Trail Duration	0.2 - 1.0 seconds
Information Duty Cycle	2.5 - 5.0 percent
Average Message Delay	10 - 80 seconds
Worst Message Delay	1 - 5 minutes

The FCC rules for meteor burst are in 90.250 and only authorizes operations for the state of Alaska. Coterminous U.S. operation is by FCC developmental authorization defined in Subpart Q of Part 90.

SkyTel note.

See "METEOR BURST SYSTEM COMMUNICATIONS COMPATIBILITY" NTIA Report 89-241, March 1989, regarding how to space MBC systems to avoid co- and adjacent- channel interference to terrestrial wireless. (This is available in the public domain on the Web: Google the identifying information above.)

SkyTel is investigating the findings in this NTIA report. It discusses easily achieved spacing, considering the SkyTel nationwide collection of large numbers of 35 and 43 MHz "geographic" exclusive-use licensed frequencies in virtually all parts of the nation, with few local incumbent terrestrial stations in use: those will not hard to protect, and to demonstrate this ahead of construction and operation.

MBC for ITS, on 35-43 MHz as SkyTel plans, will be integrated with terrestrial M-LMS (noted briefly above in this report) (M-LMS and other lower -900 MHz SkyTel holds) and also SkyTel's nearly nationwide 217-222 MHz spectrum systems. All three bands, each nearly nationwide (and together fully nationwide in coverage, with redundancy), are ideal for cost effective, highly reliable, ITS wireless coverage for all core ITS wireless applications (those most essential to transportation safety, efficiency and reliability).

SkyTel:

See other SkyTel MBC douments on the Scribd MBC Collection for background of MBC. This document is presented here to point out the following: See:

- p. 20: A past plan of the Federal Emergency Management Agency to use MBC for a nationwide "Meteor Burst Warning/ Communications Subsystem."

- p. 20: MBC for remote pipeline monitoring.

- p. 21: MBC for back-up to satellite communications, and regular telephone and microwave systems.

- p. 23: MBC backpack terminals, and MBC for two-way comms with trucks.

ATTACHMENT 6

NTIA REPORT 89-241

METEOR BURST SYSTEM COMMUNICATIONS COMPATIBILITY

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U.S. DEPARTMENT OF COMMERCE
Robert A. Mosbacher, Secretary

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for Communications and Information

MARCH 1989

Anchorage, Alaska. The transmitter and receiver frequencies are separated about 1 MHz to permit full duplex operation.

Another possible future use of the meteor burst system may be to monitor pipelines. These environmental data gathering meteor burst operations usually operate with 300-500 watt master stations and 300 watts remote. They operate in the lower part of the 40 MHz band with 20 kHz bandwidth channels.

5.3 METEOR BURST EMERGENCY COMMUNICATIONS

The Federal Emergency Management Agency (FEMA) has developed the concept for a Meteor Burst Warning/Communications Subsystem (MBWCS). The FEMA MBWCS concept, which is complementary to the landline oriented National Warning System (NAWAS), is to include 10 regional meteor burst (MB) master station terminals (MST), MB transceivers at the Emergency Operations Centers (EOC) of the 48 contiguous states, and MB warning receivers at 5000 designated warning points (including 2600 current NAWAS warning points) throughout the Nation. Coded national warning messages, injected by HF radio or landline from the National Warning Center (NWC) or Alternate NWC, will be acknowledged, automatically converted to short preformatted messages, and broadcast to adjacent master stations, State EOCs, and warning receivers. The MBWCS also will provide two-way point-to-point communications between adjacent master stations, and master stations and State EOCs within designated areas. The system is nonadaptive.

The equipment characteristics for the system are:

Transmitters: Master Stations - 10
State EOCs - 48 (Transceivers)
Power - 1 kW
Modulation - Bi-phase shift keyed (BPSK)
Warning-Omni - Communications (Pt-Pt)

Receivers: At Master Stations sites - 2-4 (approx. 24 total)
State EOCs - 48 (Transceivers)
At Warning Points - 5000

Messages: Data Rate - 4000 bps
Format - ASCII coded teletype (Pt-Pt) Binary (Warning)

Frequency: 40-50 MHz (Three frequencies for the system; each MST will transmit on one and receive on two frequencies. Each EOC will use one transmit and one receive frequency.

5.4 METEOR BURST COMMUNICATION SYSTEMS

Meteor burst communication systems operate by transmitting packets of digitized information during the channel openings. The advantage of meteor burst is that it can provide reliable communications for low-rate data and slow teletypes to and from remote sites where other modes of communication (satellite, microwave, and telephone) are unavailable or may be lost in an emergency. Previously, HF has been used in these circumstances, but HF frequencies must be changed regularly and at times HF signals can be unavailable for long periods of time due to the variances of the ionospheric properties. Meteor burst systems, although intermittent, utilize a reliable stationary communication channel.

Meteor burst system users choose transmitter power antenna size, receiver threshold, frequency, and data rate depending upon the communication requirement. For example, lower data rates are used when the message waiting time is more important than the amount of data to be transmitted in a given amount of time.

Meteor burst systems have found a place in Alaska to provide a thin route low data rate communication system for private users. The company, Alascom, provides long distance communication links across Alaska. The company operates a meteor burst communication system as a satellite back-up. The FCC (1988) provision on the use are the allowed frequencies 42.4, 44.10, 44.2, and 45.9 MHz. The base station power is limited to 2000 watts for base stations and 500 watts for remote stations. Cochannel base stations of different licensees are to be located 150 miles apart. (A waiver of the distance separation requirements is possible if a cooperative sharing arrangement can be reached.) The emission is to allow for PSK or FSK keying and the maximum authorized bandwidth is 20 kHz.

Meteor burst research is proceeding towards improving the understanding of the propagation mechanism and improving the technology and techniques (see Reference 5). There is currently considerable testing of meteor burst systems to determine the bounds on the communication capabilities (e.g., throughput, wait time) of meteor-burst systems. Some of the testing experiments have been carried out at high latitudes since meteor burst technology has both applications and advantages at high latitudes. Another subject of interest is the application of meteor burst scatter for short range BLOS communication distances less than 400 km.[8]

Meteor burst communication systems in 1987 have advanced to include the communication capabilities shown in TABLE 3.[9]

TABLE 3

METEOR BURST SYSTEM CHARACTERISTICS
(SOURCE: See Reference 9)

Adaptive Data Rates
Forward Error Correction
Networking
8000 Character Message Lengths
Average Throughput: 300 Words Per Minute
Message Wait Time: 1.5 Minutes

The meteor burst technology is continually improving and much has happened during the past five years. It is therefore difficult to extrapolate

[8]Weitzen, J.A., Communicating Via Meteor Burst at Short Ranges, IEEE Transactions on Communications, Vol. COM-35, No. 11, November 1987.

[9]Morgan, E.J., "Meteor Burst Communications: An Update," Signal, pp. 55-61, March 1988.

into the future the expected numbers and uses for meteor burst systems in the United States. One area in which progress has been made is in the size and complexity of the meteor burst equipment. Backpack terminals with easy set up are now feasible. Another application is to provide two-way communication with trucks (see Mickelson, 1989).[10] The FCC has authorized such a system to be operated on motor carrier service frequencies. The number of mobile units is expected to be in the tens of thousands.

5.5 VHF SYSTEMS

The U.S. VHF spectrum from 30-110 MHz is divided into 26 bands. These bands generally alternate between exclusive government and exclusive non-government bands as seen in APPENDIX A. There are only two bands that are shared between government and nongovernment from 30 to 50 MHz, and these are shared radio astronomy allocations. From 50-110 MHz, there are four shared bands, which are all in the 73-75.4 MHz spectrum region. These shared bands between government and nongovernment include radio astronomy from 73-74.6 MHz, fixed and mobile between 74.6 and 74.8 MHz and 75.2 to 75.4 MHz, and aeronautical radionavigation from 74.8 to 75.2 MHz.

In the 30 to 40 MHz band, the greatest use by government is for land mobile systems. The station class ML (a land mobile station) has the greatest number of assignments. In the 40 to 50 MHz band, the greatest number of assignments for a given station class is to ML. The meteor burst communication system, which is comprised of the Department of Agriculture's SNOTEL network, makeup the major assignments for the second most used station class in this band--FXH. The FXH designator is a fixed station used for the automatic transmission of either hydrological or meteorological data, or both. Most uses in this band are for land mobile systems, although aeronautical mobile and maritime mobile are also in use.

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[10]Mickelson, K. D. <u>Tracking 64,000 vehicles with meteor scatter radio</u>, Mobile Radio Technology, pp 24-38, January 1989.

ATTACHMENT 7

Spectral Occupancy at VHF: Implications for Frequency-Agile Cognitive Radios

1. SkyTel entities hold nationwide certain 35 and 43 MHz licenses especially suitable for Meteor Burst Communications (MBC): these frequencies are in the low-band VHF range.

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2. This paper indicates low-band VFH in range good for MBC (30-50 MHz) is not too congested and is suitable for frequency-agile Cognitive Radio tech. SyTel is looking to this tech for all its spectrum bands, 35-43, 200, and 900 MHz.

***Abstract*— Frequency-agile cognitive radio is a potential solution to the problem of inefficient use of radio spectrum in the 30–300 MHz (VHF) range. This is especially attractive if networks based on this technology can operate in spectrum left unused by existing users, as opposed to being allocated new spectrum through refarming. This paper presents a preliminary survey of this band in a large U.S. city, with the goal of quantifying spectral occupancy and thereby gaining some insight into the feasibility of this approach. A comparable measurement of the 25-90 MHz band in a rural environment is also presented, for comparison. In the urban measurement, it is found that sufficient spectrum is probably available: for example, it is estimated that approximately 80% of the 30–60 MHz band is essentially free of signals to within about 7 dB of the environmental noise limit at 30 kHz spectral resolution. However, these measurements are limited in duration, spatial sampling, temporal density, and spectral resolution. Requirements for a more comprehensive measurement campaign are proposed.**

I. Introduction

Frequency-agile cognitive radio is a potential solution to the problem of inefficient use of radio spectrum in the 30–300 MHz (VHF) range. In this concept, mobile radios observe the available spectrum and make intelligent, mutually-beneficial choices as to operating frequency (and perhaps other parameters) dynamically. One possible implementation is to dedicate a set of fixed frequencies having predetermined bandwidth to this application. However, this would require a reallocation of at least some portions of the spectrum, which is onerous from both a political and regulatory perspective. Also, the amount of spectrum which could be allocated would likely be very limited. An alternative approach would be to allocate no new spectrum to this mode of operation, but to instead allow frequency-agile operation in spectrum which is allocated to other uses, but which are inactive much of the time. Although this would also involve formidable challenges of a regulatory nature, this approach is perhaps somewhat more attractive because much of the VHF spectrum is currently allocated to many uses that are inactive much of the time, such as two-way push-to-talk voice communications. Thus, a cognitive radio network could conceivably share those frequencies on a non-interference basis (i.e., transparent from the perspective of the existing users) and with no coordination required outside the cognitive radio network. If a frequency-agile cognitive radio network has access to a sufficient number of such channels, then it is possible that a very large system capacity could be achieved with no new allocation of spectrum.

The goal of this paper is to begin to quantify the extent to which the present-day VHF spectrum might be able to support this concept. The relevant metric is spectral occupancy, which is defined here as the probability that a signal above a specified threshold power is detected within a certain bandwidth and a certain time span. A proper characterization of spectral occupancy in a specified area would require weeks of continuous monitoring of about 300 MHz of spectrum with a time-frequency resolution on the order of a few seconds × a few kHz, at a variety of locations. Furthermore, the sensitivity of the measurements should nominally be at least equal to the sensitivity of any receivers that might be employed. Such measurements are extremely challenging, both technically and logistically. In this paper, we instead present some results from a very short measurement conducted at one location in a large U.S. city, with the goals of providing a quick look at the state of the VHF spectrum, identifying the "low hanging fruit" in terms of spectrum which appears immediately suitable for sharing with frequency-agile cognitive radio networks, and motivating future measurements which can more properly characterize the spectrum. For contrast, a measurement taken in a relatively remote rural location is also provided.

II. Urban Measurements

A. Instrumentation

The urban measurement was conducted during a weekday afternoon from the roof of a 2-story office building inside the city limits of Columbus, Ohio. The instrumentation consisted of an AOR Model DA3000 25 MHz to 2000 MHz discone antenna connected by a long cable to an Agilent Model E4407B spectrum analyzer, which was controlled by PC. The antenna was mounted about 14 m above ground level. The data were calibrated to remove the separately-measured transfer function of the cable connecting the antenna to the spectrum analyzer. Thus, the power spectral density (PSD) indicated in this paper is that measured at the terminals of the antenna.

The spectrum analyzer was configured for linear power detection (as opposed the default "auto-peak" mode) with 30 kHz resolution bandwidth. This allowed the spectrum from DC to 300 MHz to be measured in three 90 MHz segments each consisting of 3001 contiguous channels. 30 kHz is a little

This paper also indicates that entties like SkyTel engaged in public interest wireless to assist key goals of government, could use government spectrum adjacent to their exclusive-use 35 and 43 MHz for MBC, using Cognitive Radio techniques, for additoinal capacity for those critical goals.

wider than the typical bandwidth of signals employed at the low end of the VHF spectrum. 1–5 kHz spectral resolution would be nominal, but in this case would have dramatically increased the difficulty of the measurements.

A few minutes of sweep data were collected over the course of about 5 minutes, during which every spectral channel was observed at least 400 times with a temporal resolution of about 83 μs. The data were analyzed using two different methods: (1) "Mean", in which power per 30-kHz channel is linearly averaged in time, and "Maximum" ("max"), in which the result for any given channel is the maximum power ever observed in that channel. Together, the mean and max results provide a simple characterization of the temporal behavior of a channel: For example, when the results are equal, it suggests a single transmitter which is always on and which experiences no fading (and so is probably not moving either). At the other extreme, a large difference between the mean and max measurements suggests intermittent use of the channel.

To provide a rough estimate of sensitivity, the antenna was replaced by a matched load at ambient temperature and the experiment was repeated. From this it was determined that the mean PSD of the system noise in a single sweep was less than -132 dB(mW/Hz). The minimum detectible persistent signal (MDS) after averaging is therefore about -87 dBm in the 30 kHz channel bandwidth.

It is useful to compare this to the ambient noise floor; that is, the noise present in the environment which therefore bounds the sensitivity of any receiver. This can be expressed in terms of the "median environmental noise figure" F_{am}, which is defined as the environmental noise power density relative to -174 dB(mW/Hz), which corresponds to a reference temperature of 290 K. F_{am} decreases monotonically from about 35 dB at 30 MHz to about 8 dB at 300 MHz in a "business" environment [1], corresponding to -94 dBm and -121 dBm per 30 kHz, respectively. Based on these values, the sensitivity of the measurements presented here are estimated to be about 7 dB above the environmental noise-limited sensitivity at 30 MHz, and about 34 dB above at 300 MHz. Therefore, the measurements have reasonably useful sensitivity in the low-frequency portion of the VHF band, whereas spectral occupancy at the high end of the VHF band may be significantly underestimated as the result of signals which are undetected here but could be detected by appropriately-designed receivers.

Finally, we note that replacing the antenna with a matched load provides about 40 dB isolation between the environment and the measurement system. The isolation is not perfect because VHF frequencies effectively penetrate directly into the test equipment. As a result, the "matched load" PSDs exhibit some break-through of the strongest signals, but are otherwise valid.

B. Results

Figures 1–3 show the results for 0–90 MHz, 90–180 MHz, and 180–270 MHz respectively. Prominent in these figures are broadcast TV Channel 4 with video, color, and audio

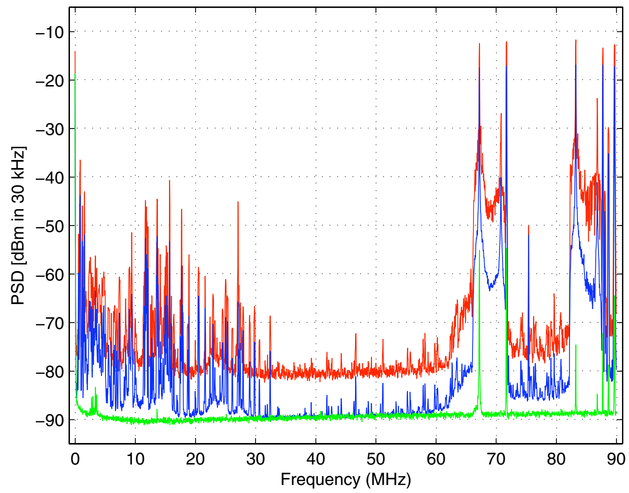

Fig. 1. Urban setting, 0–90 MHz. *Red/Top:* Max; *Blue/Middle:* Mean; *Green/Bottom:* Mean, matched load replacing antenna. (Note limited isolation in the matched load case; see text.) Resolution: 30 kHz.

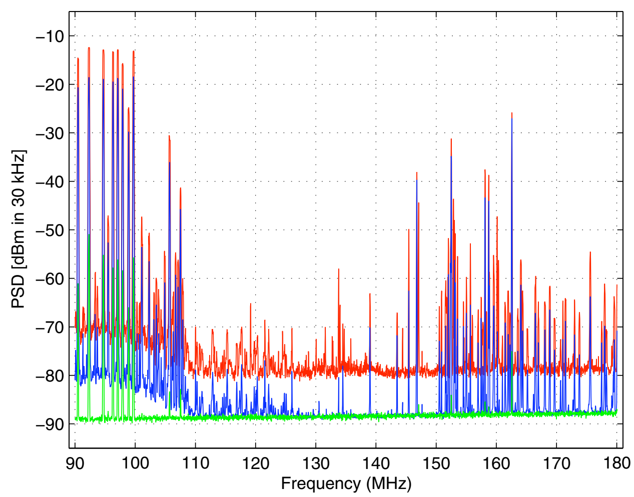

Fig. 2. Urban setting, 90–180 MHz. *Red/Top:* Max; *Blue/Middle:* Mean; *Green/Bottom:* Mean, matched load replacing antenna. Resolution: 30 kHz.

subcarriers at 67.25 MHz, 70.83 MHz, and 71.75 MHz respectively; Channel 6 (83.25 MHz, 86.83 MHz, and 87.75 MHz); Channel 10 (193.25 MHz, 196.83 MHz, and 197.75 MHz); and commercial broadcast FM (various stations ranging from 88–108 MHz). The remaining signals are predominantly mobile radio transmissions. There is not much difference is observed between the mean and maximum PSDs, suggesting high duty cycle for channels which are actually used.

Next we attempt to quantify spectral occupancy. Note that there are large portions of the spectrum which are occupied by very strong, relatively broadband signals – namely, broadcast TV and FM stations – nearly all of the time. Clearly, there is not much value in including those portions of the spectrum in calculations of spectral occupancy. Instead, we shall consider two segments of the VHF band which appear promising: 30–60 MHz, and 140–180 MHz. 116–140 MHz is

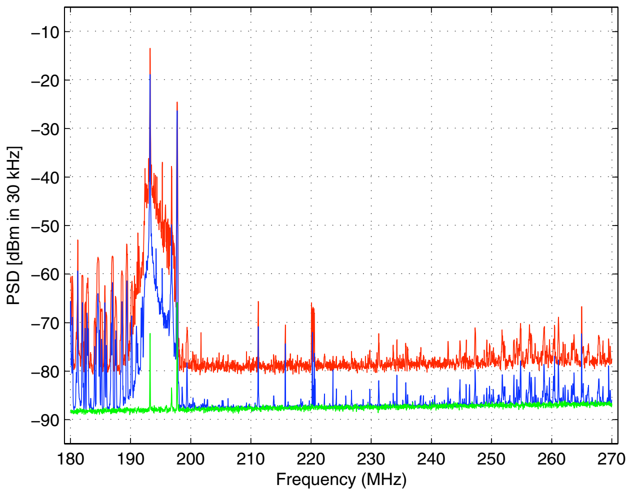

Fig. 3. Urban setting, 180–270 MHz. *Red/Top:* Max; *Blue/Middle:* Mean; *Green/Bottom:* Mean, matched load replacing antenna. Resolution: 30 kHz.

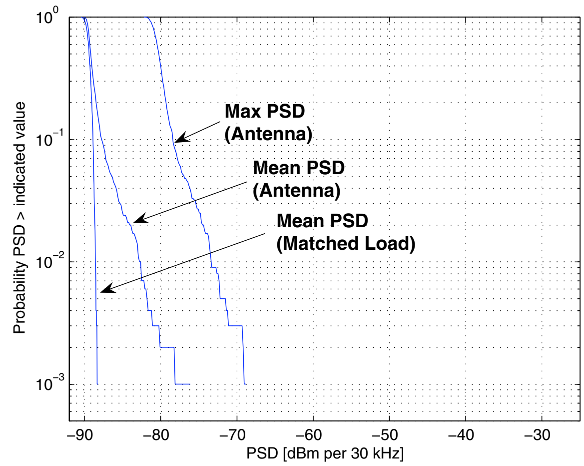

Fig. 4. CDF of spectral occupancy in 30–60 MHz. The three curves corresponds to the data shown in corresponding curves in Figure 1.

avoided because this band includes aviation communications and satellite downlinks, which may not be good candidates for sharing with cognitive radio.

The spectral occupancy for the 30–60 MHz band in shown in the form of a cumulative distribution function (CDF) in Figure 4. The CDF is taken directly from the data shown in Figure 1, as opposed original (sweep) data, and thus represents only spectral, not temporal occupancy. Note that the observed "noise floor" is about 8 dB higher for the max PSD than for the mean PSD, which is an expected consequence of the Gaussian distribution of the noise. It is interesting to note that about 80% of the channels exhibit mean power not significantly above the sensitivity limit, which suggests that the spectrum is indeed quite sparsely used, which is encouraging. Also encouraging is the relatively low maximum powers observed, as this implies manageable dynamic range requirements for a receiver which must continuously monitor this entire band for openings.

A related consideration is the contiguous bandwidth available between occupied channels. To quantify this, the number of open spaces between occupied channels and the bandwidth of these openings was analyzed, with results shown in Figure 5. At a threshold level of -88 dBm per 30 kHz, there were 40 openings of 30 kHz or larger in the 30–60 MHz band mean PSD, with the mean opening being 651 kHz wide and the maximum opening being about 2.3 MHz wide.

Figures 6 and 7 show the analogous results for the 140–180 MHz band. In this band we see about the same number of channels ($\sim 80\%$) which exhibit mean power not significantly above the sensitivity limit, but relatively large maximum powers. At a threshold level of -87 dBm per 30 kHz, there were 67 openings of 30 kHz or larger in the mean PSD, with the mean opening being slightly narrower (411 kHz) and the maximum opening being about 3.3 MHz wide. However, because the sensitivity of the measurement system is somewhat worse in this band compared to the 30–60 MHz band, these findings should be interpreted with care.

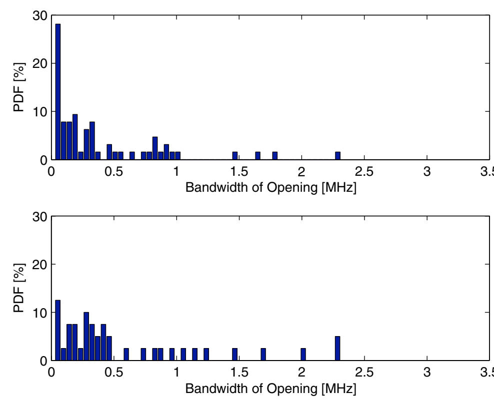

Fig. 5. PDF of openings in the 30–60 MHz band. *Top:* Max PSD (-79 dBm threshold), *Bottom:* Mean PSD (-88 dBm threshold).

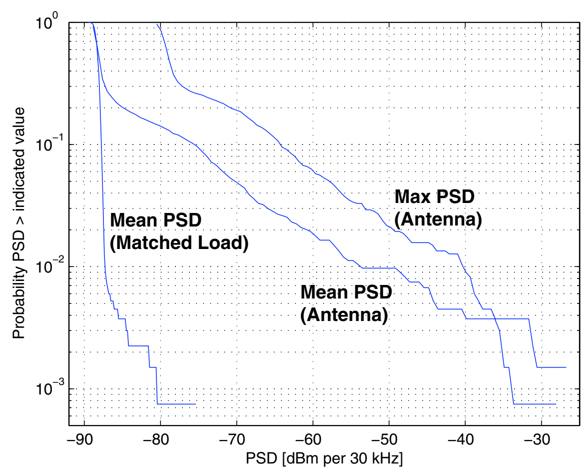

Fig. 6. CDF of spectral Occupancy in 140–180 MHz. The three curves corresponds to the data shown in corresponding curves in Figure 2.

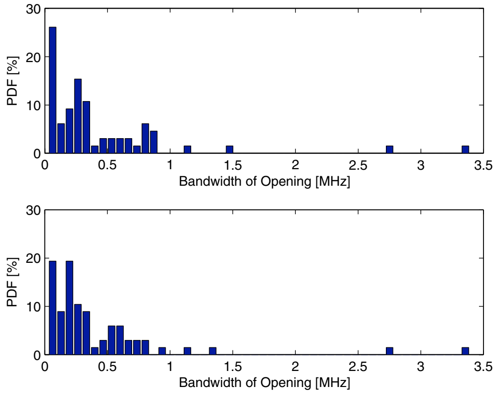

Fig. 7. PDF of openings in the 140–180 MHz band. *Top:* Max PSD (-77 dBm threshold), *Bottom:* Mean PSD (-87 dBm threshold).

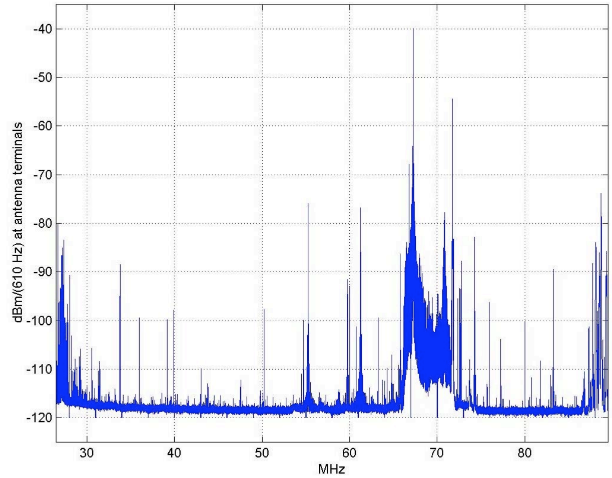

Fig. 8. Rural setting, 25–90 MHz. Mean PSD. Resolution: 610 Hz.

III. Rural Measurement

The sensitivity of the above measurements is limited by the high noise figure of the instrumentation. Better sensitivity would require a preamplifier at the antenna; however the additional gain would result in the generation of significant levels of intermodulation (due primarily to the strong broadcast TV and FM signals), which are difficult to discriminate from *bona fide* signals. It is possible to achieve better sensitivity at rural locations, where broadcast signals tend to be weaker. Of course, one might expect the spectral occupancy to be different in a rural region as well. Nevertheless, it provides useful context to compare the above results, obtained in an urban area, to those obtained from a rural area.

Measurements using different equipment were performed at the Pisgah Astronomical Research Institute (PARI), located at a mountainous rural site near Rosman, NC. In this case the antenna was a horizontally-oriented broadband "fat" dipole (described in [2]) with good performance from 30 MHz to 90 MHz, connected to an "active balun" preamplifier with sufficient gain to set the noise figure at about 5 dB. This was connected using a long cable to a custom-built fast Fourier transform (FFT) spectrometer, which measures PSD in a 4 MHz span from anywhere in the range 30–90 MHz, with a 610 Hz channel width. The MDS after a few minutes of integration is about -145 dB(mW/Hz), which is 13 dB better than the urban measurements described above. Figure 8 shows a typical measurement, in this case the "mean" result only. Broadcast TV channels 2-6 are all detected (through their narrowband video and audio carriers), although all but Channel 4 are very weak. It is difficult to make any conclusions about the temporal aspect of mobile radio activity from this measurement, but it is clear that there is very little activity detected at a level greater than -110 dBm per 610 Hz.

IV. Implications for Cognitive Radio

It is noted that the spectral occupancy is indeed sparse in the measurements reported here. There is very little evidence of persistent activity above -87 dBm per 30 kHz in the urban setting, or above -110 dBm per 610 Hz (-93 dBm per 30 kHz) in the rural setting. In the urban setting, 30–60 MHz and 140–180 MHz were observed to be possible candidates for frequency-agile operation. In these bands, 40 and 67 openings (respectively) were found with bandwidths ranging from less than 30 kHz to greater than 3 MHz. However, it is possible that the 140–180 MHz band statistics could change if the sensitivity of the measurement in that band improves; see the discussion in Section II-A. Also, it should be noted that in other locations, broadcast TV stations using different channels may be dominant. Nevertheless, these are generally positive findings with respect to the prospects for frequency-agile cognitive radio.

The measurements presented here are crude and additional effort is required to develop a compelling assessment. In particular, future measurements should strive for continuous observation at multiple locations over long ($\sim$weeks) periods with time-frequency resolution of 1 kHz $\times$ 1 ms (the latter corresponding to a reasonable lower limit on the channel coherence time). Sensitivity should nominally be comparable to the expected noise floor described in [1]. These are challenging requirements but the resulting data are essential for a compelling assessment of the feasibility and likely capacity of frequency-agile cognitive radio networks which operate in non-allocated spectrum on a non-interference basis with the primary users.

References

[1] International Telecommunications Union, *Radio Noise*, Recommendation ITU-R P.372-8, 2003.

[2] K. P. Stewart *et al.*, "LOFAR Antenna Development and Initial Observations of Solar Bursts," *Planetary & Space Science*, Vol. 52, No. 15, December 2004, pp. 1351–1355.

SkyTel intends a spectrum survey in its bands and some adjacent spectrum, including in the 30-50 MHz range.